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SHIP ANALYZERS

**ANALOG COMPUTERS FOR EFFICIENT
SHIP CALCULATION**

Redactor

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M O T T O :

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„... the manner an architect writes about his new architectural compositions should be applied by a mechanical engineer, too. A mechanical designer need not be too modest and thus satisfy himself with the presentation of only developed and recognized designs. He must write about his new technical conceptions as well.“

(Prof. Ing. V. FARMAKOVSKI, academician, in the foreword to his book „Termotehnika parne lokomotive“, Beograd, 1947)

P R E F A C E

The period after World War II has been characterized by an ever increasing use of modern computing machines in all branches of engineering sciences and routine work. But, as a matter of fact, naval architecture and shipbuilding industry in general cannot boast of being among the first users of these superb tools of modern times. For, it is only in the recent years that modern computers have been introduced here and there into this field (Refs. [10], [11], [20], [21], [22], [23]).

However, the full use of computing machines is particularly essential with the problems of naval architecture which call for innumerable series of calculations to be made where most of the data remain constant and only a tiny portion of them are varied.

As far as modern computing techniques have been used in the field of naval architecture, all kinds of ship calculation have been so far mainly performed by digital computers (Refs. [11], [20], [21], [22], [23]). It is quite understandable, since digital computers are mostly general-purpose machines and thus, once provided for performing various calculations in different departments of a company, they have come to be used also by naval architects.

Conversely, general-purpose analog computers are mainly incapable of being directly used in the field of the theory of naval architecture.* And as to the special-purpose analog computers, their development line reads „problem \rightarrow computer“, i. e., the instrument is formed after the problem. Therefore such instruments are extremely rare (in naval architecture). To the author's knowledge, there is only one special-purpose analog computer existing to-day which is intended primarily for naval architect's calculations (American computer BUSAC, Ref. [10]).

Thus, the reasons are clear why a relatively poor use has been made of the analog computing techniques in naval architecture, so far.

* By the theory of naval architecture the geometry of the ship's hull is meant here.

VIII

Nevertheless, the application of analog computing techniques in the field of naval architecture is extremely advantageous. As a matter of fact, analog computers are generally much cheaper than digital ones; they are much easier to operate, too. Thus, they are bound to be applied by a large number of users, small shipyards and even private consulting naval architects rather than to be restricted only to „calculating centers“ and big companies as the case is with bulky and expensive digital computers.

Therefore, this paper is written with a view to draw the attention of naval architects to the possibilities offered to them by the modern analog computing techniques. But, in view of the fact that naval architects in general are not familiar with either digital or analog computing technique, the introduction and many subsequent chapters of the paper have been presented on the basis of mechanical variants of computing instruments. For, though mechanical computers are rather outdated, they are very easy to understand and lend themselves readily for demonstration of the basic principles of computing techniques. As a matter of course, electrical, electronic, optical and other variants of modern analog computers designed for the naval architecture („ship analyzers“ as they were called here) have also been presented at a later stage in the paper.

Among the presented instruments the direct-current analog computers based on the so-called „model principle“ of the pick-up assembly appear to be the most adequate ship analyzers. But a very promising instrument is also the one-dark-camera optical computer which, among other things, can also allow for Smith's effect. Damaged-stability calculation can also be performed by this instrument and that on the basis of the real permeability of each of the compartments rather than on the global permeability coefficients.

Apart from the presentation of a number of new instruments a possibility has also been suggested in this paper of using general-purpose analog computers in the field of naval architecture. This can be achieved by the attachment of a „model“ pick-up assembly to any of the general-purpose analog computers comprising 20 to 30 function generators.

In summary, it can be said that ship analyzers are bound to release the naval architect from tedious and time-consuming routine-calculation work, so that his abilities may be better employed. This evidently would bring about a considerable improvement in construction of modern ships. (For more details in this respect the reader is referred to the Chapter „Concluding Considerations“). The saving in time achieved by ship

analyzers can be recognized as a real revolution in the designer's practice, time reduction amounting to one hundred times or so. It should be also pointed out that, beside covering the standard scope of calculations, ship analyzers might promote advancement in the so far unexplored fields in the theoretical realm of naval architecture.

The purpose of the paper has been, *first*, to point to the great possibilities for the application of the analog computing techniques in the field of ship calculation and thus to instigate a more lively research work in this direction, and, *second*, to indicate thereby some of the possible ways of approach to this. Thus, if both naval architects and analog-computing specialists — stimulated by the present paper — take a greater interest in remarkable prospects of the analog computing techniques in the field of naval architecture, the purpose of this discussion may be considered completely fulfilled.

Grateful acknowledgments are due to Prof. Dr. Ing. N. Zrnić, Dr. Ing. R. Tomović and Ing. Lj. Radanović who made valuable suggestions in the course of the preparation of the paper. Particular thanks are also due to Prof. Dr. Ing. D. Veličković, director of the Mechanical Engineering Institute, for the publication of the paper, to Mrs. J. Veličković who kindly revised the references as well as to Miss A. Rudicina who studiously revised the English edition of the paper and offered many valuable suggestions.

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B. A. DJODJO

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A) INTRODUCTION

Text-books on naval architecture usually have a number of chapters dealing with different problems and corresponding numerical methods to handle them. However, such a division into many separate chapters, although justifiable from the teaching point of view, may turn out to be rather misleading: It prevents an architect from taking a long view of the whole field and from grasping the fact that there are hardly more than two main problems underlying the whole range of calculations within the theory of naval architecture. (The term „theory of naval architecture“ is used here in its narrower sense; only the geometry of the ship's hull is involved, hence propulsion, strength of ship, etc., are excluded).

The problem No. 1 is as follows: An arbitrary water line is drawn either on the longitudinal plan or on the transversal plan of a ship, and the task which is set then is to determine the displacement and the co-ordinates of the center of buoyancy.

The problem No. 2 is this: For the arbitrary water line from the problem No. 1 it is necessary to determine the area, moment of area and moment of inertia of the water plane. Moment of area and moment of inertia are to be determined for both the longitudinal and the transversal axis through the center of gravity of the water planes.

The reason that these two problems have not been underlined as fundamental ones so far lies partly in the fact that they show themselves in very different aspects, which makes it difficult to comprehend them as such. At one time the arbitrary water line is a straight line, at another it has the form of a wave. Now it is drawn on the longitudinal plan („Profile“ or „Sheer Plan“), and somewhat later on the transversal one („Body Plan“). Sometimes the problems are set directly, and sometimes the reverse is the case: For example, the displacement and the co-ordinates of the center of buoyancy are set and the water line to correspond to these data is to be found out.

Let us adopt one designation consisting of three symbols in the brackets. Let first symbol mean the number of the fundamental problem [1 or 2], the second the plan on which the water line is drawn [L = longitudinal, T = transversal] and the third the direction of the problem [D = direct, I = indirect].

Then, to check the statement about the two problems as fundamental ones, let us first make a survey of all the major problems encountered in the theory of naval architecture:

I) *Curves of form* („Kurvenblatt“ in German). Some 15 curves are included here. All of them are presented on a basis of the draft. To plot the curve of displacement a series of problems [1; L or T;D] has to be solved. The same series gives data for plotting the curve of the loci of the centers of buoyancy (vertical and longitudinal) and the curve of the block coefficient. To plot the curves of metacenters a series of problems [2;L and T;D] has to be solved. The same series gives data for plotting the curve „tons per inch“, the curve of the coefficient of water planes, that of the moment to change trim 1 inch as well as that of the loci of the centers of gravities of water planes, etc.

II) *Launching*. In launching calculations there is a series of problems [1;L;D] and [1;L;I] to be solved.

III) *Locking*. Here also a series of problems [1;L;D] has to be solved.

IV) *Stability at large angles of inclination*. This problem is in essence nothing else but a multitude of the problems [1;T;D].

V) *Location of wave profile* over the ship profile when calculating longitudinal strength. Here we meet the problems [1;L;I].

VI) *Flooding — Compartmentation*. In the first stage when a series of the water lines tangential to the margin line are drawn and the added weight and the shift of the center of buoyancy are determined, the question is of the problems [1;L;D]. Later on, when the floodable lengths are determined, the problems [1;L;I] are encountered but only for the parts of a ship rather than for the ship as a whole.

VII) *Grounding*. Here we have the problems [1;L or T;D].

VIII) *Russo's diagrams*. Here a lot of problems [1;L and T;D] as well as [2; L and T;D] occur.

There are still some problems which are by far minor than these ones, and which more or less reduce to the fundamental problems as well.

A word of explanation is necessary here: When expounding to the student for example the Chapter „Launching of Ships“, 95% of time is

spent explaining launching process, determination of pressure on ways and other features. Determination of buoyancy and of its moment is taken as known to the student, as it really must be at that stage of course. But, when calculating in practice the launching of a ship, then, quite conversely, 95% of time is spent in volumetric calculation of the hull, all the other calculation turning out to be mere statics.

Similar conditions occur with other „chapters“ of the theory of naval architecture, too.

So, it is from this standpoint, i.e., from the point of view of a practical naval architect (and not from that of a teacher) that we speak of the mentioned problems as being fundamental ones.

Thus, these two problems obviously proving to be fundamental ones, we feel that a focussing on them is indispensable. Indeed, if these two problems were efficiently solved, a new era would open in the sphere of calculations which the naval architect has to cope with.

Here a new path is followed towards this aim. No numerical method has been elaborated, but a discussion of the possibilities of applying analog computing techniques has been presented. Thus a series of analog computing instruments (called „ship analyzers“) has been conceived and discussed in the paper.

I) DESIGNATIONS

Before entering into the description of the instruments, let us lay down a basis for the designations. The following designations, adopted in connection with the two co-ordinate systems O, x, y, z and O', x', y', z' shown in Fig. 1, will be used in our discussion:

$A_i = y_i(z) =$ contour line of half-breadths of ship of the i -th cross section in function of the draft z .

$A_j = x_j(z) =$ contour line of the lengths of ship of the j -th vertical fore-and-aft section in function of the draft z .

$A_k = y_k(x) = [x_k(y')] =$ contour line of the half-breadths of ship of the k -th water-plane section in function of the length of ship x (or contour line of the lengths of ship of the k -th water-plane section in function of the breadth of ship y').

$A_i, A_j, A_k =$ areas enclosed by the above-mentioned lines respectively, i. e., the areas (determined by argument limits) of cross sections, of vertical fore-and-aft sections and of water planes respectively.*

$M_i(y') =$ moment of A_i with the lever-arms parallel to the axis y' , hence the moment about the vertical axis (as z') formed by intersection of A_i -plane with co-ordinate plane O', x', z' . [$M_i(y)$ would mean the moment about the vertical axis (as z) formed by intersection of A_i -plane and co-ordinate plane O, x, z].

$M_i(z) =$ moment of A_i with the lever-arms parallel to the axis z , hence the moment about the horizontal axis (as y) formed by intersection of A_i -plane and co-ordinate plane O', x', y' . [$M_i(z') = M_i(z)$, since $|z'| = |z|$].

$M_j(x), M_j(z) [= M_j(z')], M_k(x), M_k(y') =$ analogous to the above.

$J_i(y'), J_i(z), J_j(x), J_j(z), J_k(y'), J_k(x) =$ moments of inertia of the same planes and about the same axes as above.

* Formally, this formulation is contradictory, since $y_i(z)$ and $y_k(x)$ lines mean only *half-breadths* of ship so that the areas enclosed by these lines should be multiplied by 2 in order to obtain the full values of the areas of resp. cross sections and water planes. Nevertheless, we shall adhere to the designations **A** meaning invariably full values of areas of ship's sections so that a multiplication by 2, if necessary at all, will be supposed (even in the formulas to follow!) to be *tacitly* performed when transferring A-values into **A**-ones.

As we are in the domain of the analog computation where the multiplication by a constant factor affects but the scale factors of the results, such a convention is fully acceptable. Thus *practically* the formulation relating to the areas enclosed by the mentioned contour-lines as those of the ship's sections is yet holding.

D = displacement of ship.

$M(x)$ = moment of displacement of ship with lever-arm parallel to the axis x , hence the moment with reference to the O, y, z -plane.
 $[M(x') = \text{same with reference to the } O', y', z'\text{-plane}].$

$M(y')$ = moment of displacement of ship with lever-arm parallel to the axis y' , hence the moment with reference to the O', x', z' -plane.
 $[M(y) = \text{same with reference to the } O, x, z\text{-plane}].$

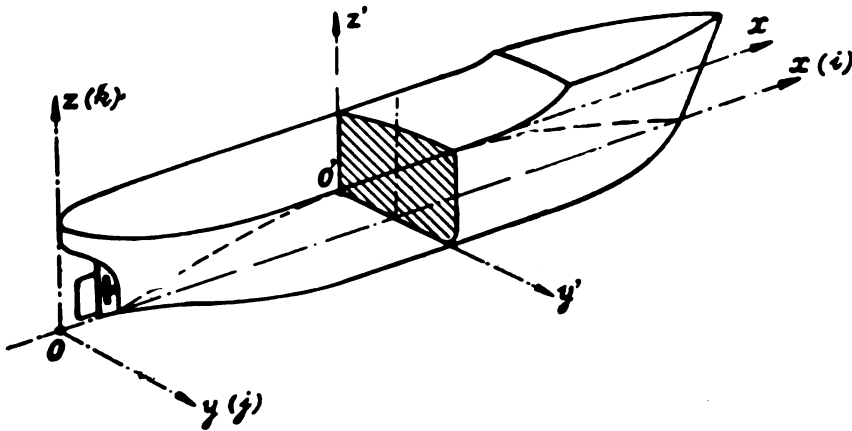


Fig. 1

$M(z)$ = moment of displacement of ship with lever-arm parallel to the axis z (or z'), hence the moment with reference to the O, x, y - (or O', x', y')-plane.*

x_0, y_0, z_0 = co-ordinates of the center of buoyancy of ship in the system O, x, y, z .

x'_0, y'_0, z'_0 = co-ordinates of the center of buoyancy of ship in the system O', x', y', z' .

Assemblies, subassemblies, etc., of the instruments will be designated by small letters (a, b, c, \dots), whilst the elements themselves will be denoted by numerals ($1, 2, 3, \dots$). Commonly accepted mathematical designations (like $x, y, z = \text{co-ordinate axes}$, $f = \text{function}$, $d = \text{differential}$, etc., as well as those from electricity ($C = \text{capacitance}$, $R = \text{resistance}$, $Z = \text{impedance}$, etc.) are exempted from this rule.

* See also footnote on page 45.

B) ONE-INTEGRATION INSTRUMENTS

1) MECHANICAL INSTRUMENTS

a) FUNDAMENTAL PROBLEM No. 1

An approach to the concept of instrumentation may be best presented by means of an example. Thus, suppose the task is set to locate a wave profile over the ship profile (problem of balancing the ship on the wave). This is the problem of the kind [1; L; I]. It means in some way a generalization of the problems [1; any; any], as the water line is not a straight line here but a wave-form line, and as the problem itself instead of being a direct one, is an indirect one (indirect problems consist actually of a series of direct problems by means of which, by trial-and-error method, i. e., by hunting for an answer satisfying balance conditions, indirect problems can be solved). This is just the reason why we take this problem for our example; the instrument once capable of dealing with this problem, other problems of the kind [1; any; any], as simpler ones, can necessarily be solved by it.

The normal way of solving the problem of wave location is to put the standard wave profile, drawn on a sheet of tracing paper, over the set of stations (representing the ship's cross sections) and their Bonjean curves (lines representing the area of the section in function of the draft), then the ordinates of latter curves at intersection points (wave profile and station) are read off (Fig. 2) and integrated (treated by trapezoidal or Simpson's multipliers and summed), so that the displacement is obtained. Then the same ordinates are first treated by multipliers representing lever-arms, then integrated, and so the moment is obtained. By dividing the value of the moment by that of the displacement the position of centroid is determined. If both the displacement and the position of the centroid are not equal to the values set by the problem, the process is repeated and the same procedure is performed continually until a satisfactory location is achieved.

To relieve this wearisome work, the following could be done:

Bonjean curves, as integral lines, are necessarily monotonic curves. Hence they can very easily be materialized, i. e., represented by steel tapes,

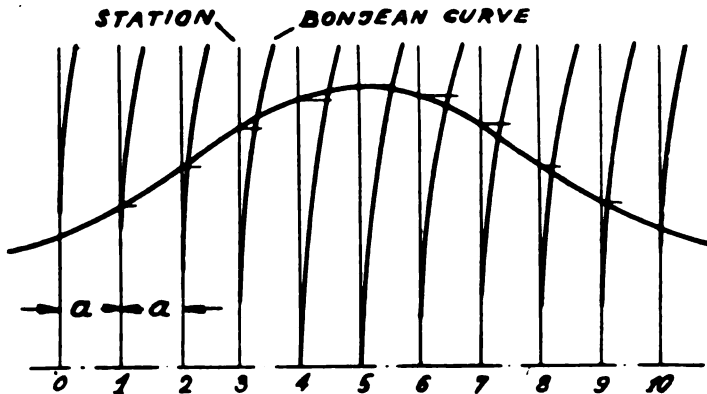


Fig. 2

moulds, etc. For the rest, procedures very similar to these are encountered in the routine work of naval draftsmen when drawing ship lines with the aid of thin splines of wood or other flexible material.

So we shall first form a series of elements represented in Fig. 3 where by 1 the steel tape representing Bonjean curve is designated and by 2 a bar called „bridge“. Steel-tape is fixed to plate 37.

Then we shall set all the bridges in one horizontal plane (Fig. 4) so that under every bridge 2 there will be a steel tape 1. The bridges will be arranged in the same order, and will be disposed in proportionally the same distances „a“ as are the ship sections to which they correspond with the original ship. The „base“ line 0—0 of the instrument will correspond to the keel of the ship thereby.

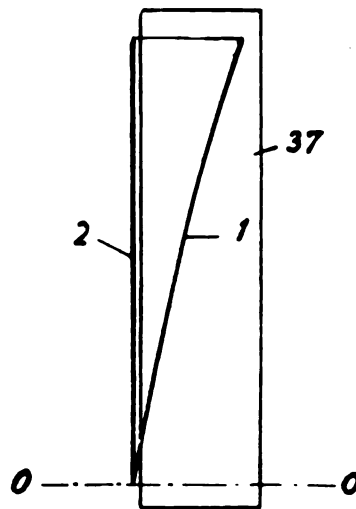


Fig. 3

Then on each bridge one carriage 3 will be put (Fig. 5) with a vertical guide through which needle 4 can slide. The needle is charged by the weight Q so that it leans on the tape 1. So the bridge is actually a traversing along which slides the carriage whereby the needle — by moving vertically — follows the form of the tape 1.

Therefore the whole complex consisting in this case of steel tape 1, plate 37, bridge 2, carriage 3 and needle 4 will be called function generator. Function generators as such — hence those of other constructions as well — will be designated in the sketches by b . The whole set as such of function

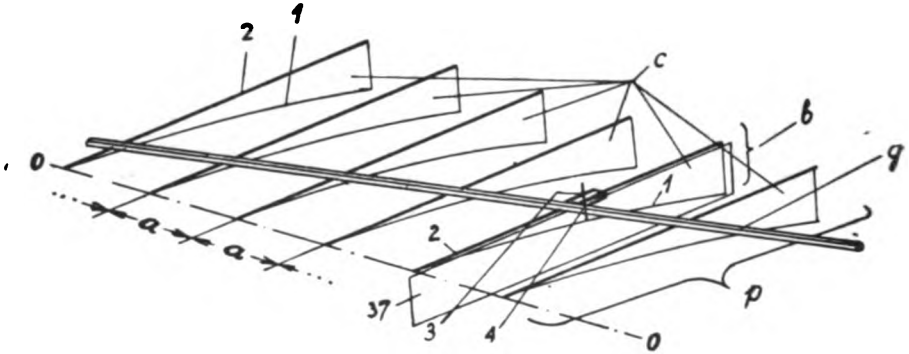


Fig. 4

generators b will be designated by c . Hence b is a function generator of any type representing a station, i. e., a ship's section, whereas c is the assembly of all the function generators b , i. e., of all the stations representing thus the whole ship.

If all the carriages be pushed by a materialized standard wave (a bar which is straight or in the form of a wave and which will be called the „water-line simulator“ and will be designated by g), the needles will continually „read off“ the instantaneous values of their Bonjean curves.

Thus the „pick-up“ assembly p (Fig. 4) of our instrument has already been formed. It consists of a set of function generators b disposed in a specific way (distances „ a “) representing the ship, and of a bar called water-line simulator g , representing the water line. Thus the pick-up assembly p as a whole is a **model of the ship in her environment**. It makes possible for the „ordinates“ of all the function generators to be „read off“ *simultaneously* and that in accordance with the position of the real water line against the real ship.

If the integration by the trapezoidal rule is assumed, hence the rule whereby all the coefficients are equal to 1 (except the end ones, but it will be explained how to allow for that at a later stage) and whereby the stations, i. e., the „bridges“ 2 are disposed equidistantly, all that remains to be done now is to transmit these values, i. e., the movements of the needles, to an adder (let us designate it by h).

The adder of a very simple design is that represented in Fig. 6. It is usually referred to as „loop-belt differential“ (Ref. [4]). Here the position of the tension weight P continually indicates the double algebraic sum of all the movements delivered to the lower pulleys 5.

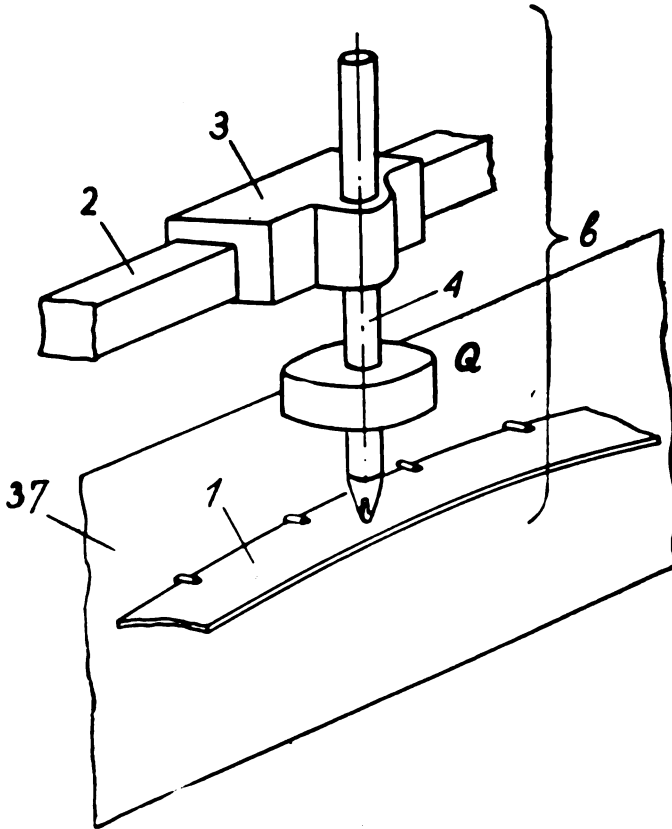


Fig. 5

Hence in a set in Fig. 7 — where for the sake of clearness only one bridge 2 and one tape 1 have been drawn while the others have been supposed (other elements shown in Fig. 7 will be explained later on) — one can arbitrarily move the water-line simulator g against the set of bridges and thereby continually read off the instantaneous values of the displacement at the output terminal by the weight P (scales of Bonjean curves and of bridges, coefficients, etc., being taken into account beforehand, i. e., when drawing the scale of the ruler 11).

It is evident that the relation

$$Q > 2P \quad (1)$$

must hold for the cables 8 and 9 to be constantly pulled tight, and for the needles 4 not to be lifted from the tapes 1 thereby. Besides, the cables must be inextensible.

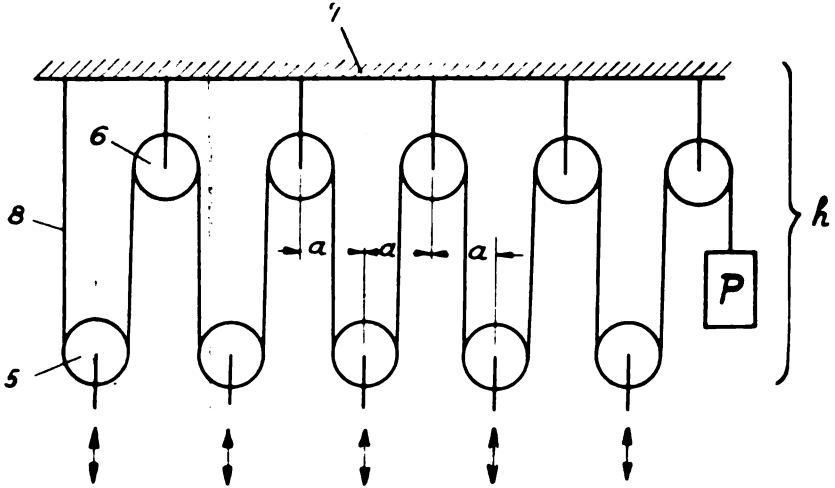


Fig. 6

It will be noticed that the water-line simulator g has the form of a wave in this case. Needless to say, however, that it may be also straight if the problem calls for this.

Besides, owing to the application of the trapezoidal rule, only the adder h is required to receive the data delivered by the pick-up assembly p . Other rules would call for a multiplier-adder in this place. Multiplier-adders as such (hence no matter of which type) will be designated by h in our sketches (hence in the same way as adders, since adders are only a derivation from a more complex unit such as a multiplier-adder). As there will be a number of them (adders and multiplier-adders) in one instrument, they will be designated by h, h', h'', \dots , etc.

As to the moment of the displacement in our problem of wave location a similar adder h' (in fact a multiplier-adder) with the tension weight P' is included in the instrument behind the foreground adder h (Fig. 7). The movements of the needles are not transmitted directly to the lower pulleys of this adder, but are first allowed to pass through the transmission gears 12 which allow for the lever-arm coefficients. So if the left-end bridge were taken as reference station (ordinate), and designated as the bridge No. 0, and if there were n ordinates (bridges) in all, then the transmission ratio i of any bridge No. j should be

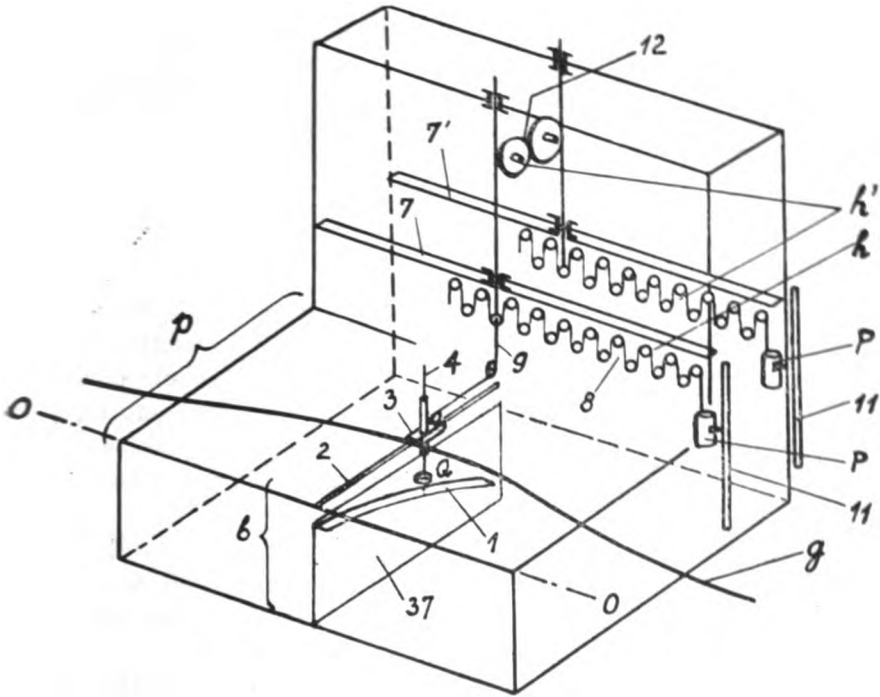


Fig. 7

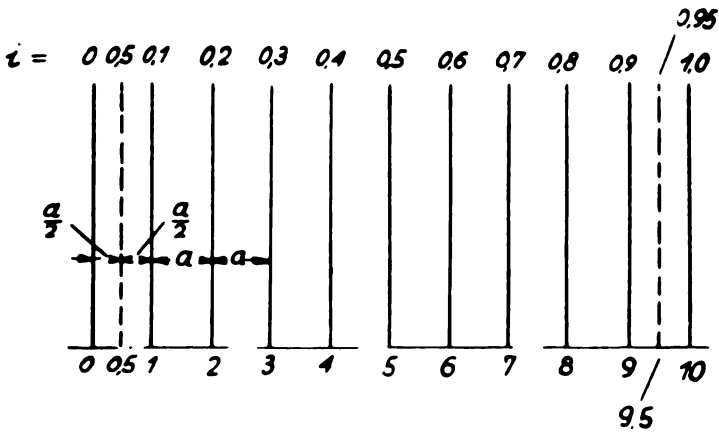


Fig. 8

$$i = \frac{j}{n-1}. \quad (2)$$

Hence the transmission ratio of the gear of the right-end bridge would be $i = 1.0$ (an example for $n = 11$ is given in Fig. 8).

Transmissions 12 might be made as gears, leverages, etc. After the introduction of the second adder the relation

$$(Q - 2P) > 2P' \quad (3)$$

should be satisfied.

If each ruler 11 in Fig. 7 is included in a circuit as shown in Fig. 9, and if the indexes on the rulers are put beforehand at the marks set by the problem, then the operator might quite arbitrarily move the wave (water-line simulator g) along the bridges. The position of the wave whereby both bells start ringing is the solution.

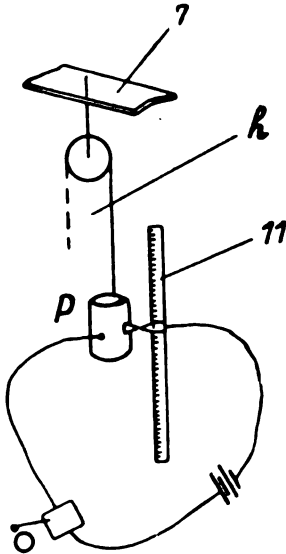


Fig. 9.

Thus the problems [1; L; I] may be solved like a child's play as well as the problems [1; L; D], these being only the special cases of the fore-mentioned ones.

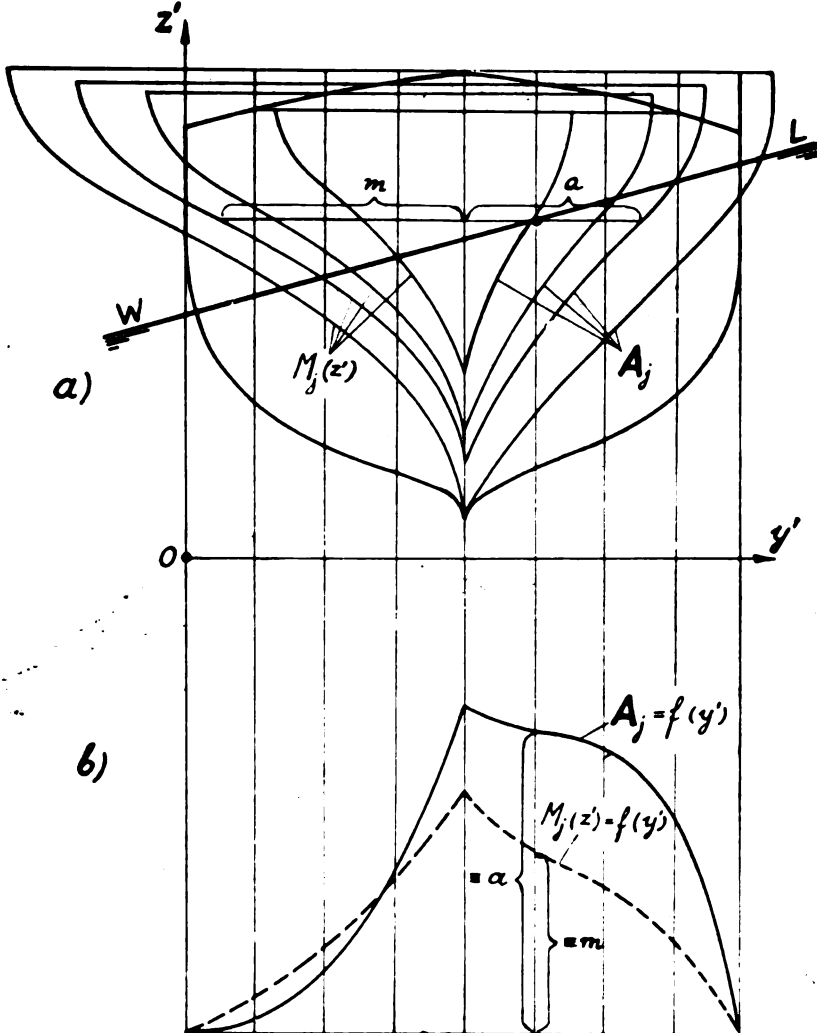
In the preceding articles of this chapter we have discussed the work done on the ship's longitudinal plan.

The transition to the work on the transversal plan does not call for any modification of the instrument. The transition is quite formal and all that is to be done is to readjust the tapes 1 so that they represent now the areas of the buttock-and-bow lines (instead of the areas of the cross sections, i. e.,

Bonjaen curves, which was the case when working on the longitudinal plan). These curves are also monotonic (while integral lines) and consequently are easy to be formed by steel tapes.

When working on the longitudinal plan, we were in the system $0, x, y, z$ (Fig. 1 — base-line 0—0 of the instrument corresponded to the axis $0, x$), and the second adder h' delivered the values of the moment $M(x)$ (wherefrom, through division by the displacement D , the leverage of the center of buoyancy x_0 could be obtained). When working now on the transversal plan, i. e., in the system $0', x', y', z'$, (Fig. 1 — base-line 0—0 of the instrument corresponds to the axis $0, y'$), the second adder will

deliver the values of the moment $M(y')$ (wherefrom the value y'_0 can be derived). Hence the instrument — at this stage — gives always the displacement (first adder h) and the moment of displacement (second adder h') with the lever-arms which are perpendicular to the ship sections represented by the function generators.



Figs. 10a and 10b

When working on the longitudinal plan z_0 is usually considered irrelevant ($z_0 =$ vertical position of the center of buoyancy), the angles of inclination on the longitudinal plan being very small. But when working

on the transversal plan the value of z'_0 is very important, the angles of inclination being very large here. Hence it is required to get both y'_0 and z'_0 here, i. e., to obtain a diagram like that in Fig. 11.

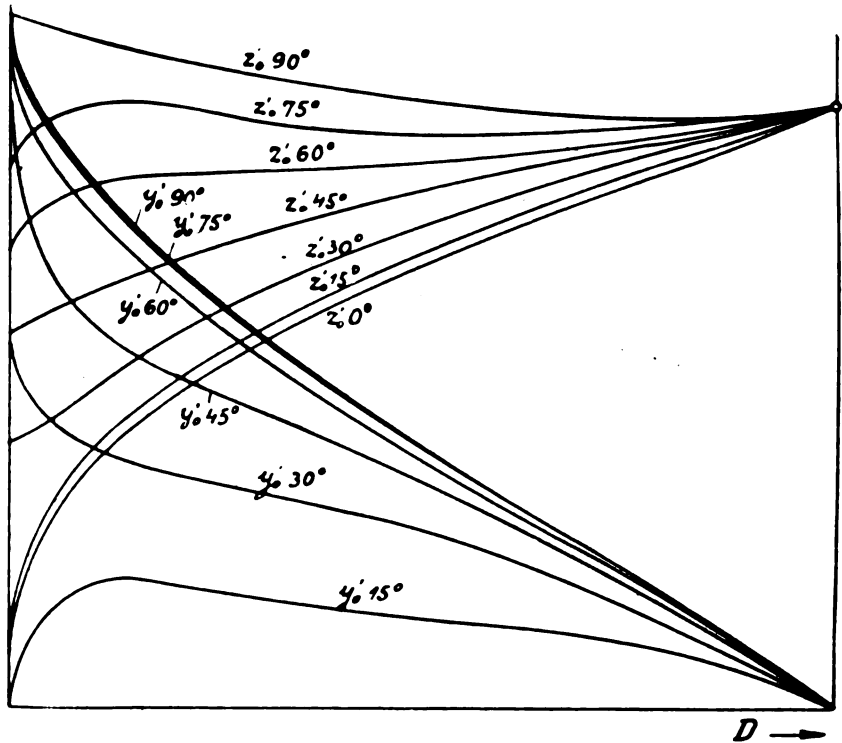


Fig. 11

There are three ways of obtaining z'_0 by means of the instrument:

Method No. 1 — The tapes are adjusted to represent the areas of the buttock-and-bow lines and a series of the value D and $M(y')$ (i. e., y'_0) is obtained by the instrument for different positions of a straight water line (for both ship upright and ship inclined). Hence, we have the diagram in Fig. 12.

Then we use Kempf's auxiliary construction to obtain the values z'_0 . That is, we choose an arbitrary displacement D_i in Fig. 12 and lay off its values y'_0 in Fig. 14. Then we assume that the centers of buoyancy of the emerged and immersed wedges lie on the line of symmetry of the small angle $\Delta\varphi$ to which the ship is being heeled (Fig. 13). This entails transferring the center of buoyancy of the ship to be parallel to this line of sym-

metry. Hence if the lines in Fig. 12 run for the values 0° , 15° , 30° , 45° , ..., we draw from F_0 in Fig. 14 a line $7,5^\circ$ to the horizontal and so get F_1 ; from F_1 we draw a line $22,5^\circ$ to the horizontal and so get F_2 and so on. The values

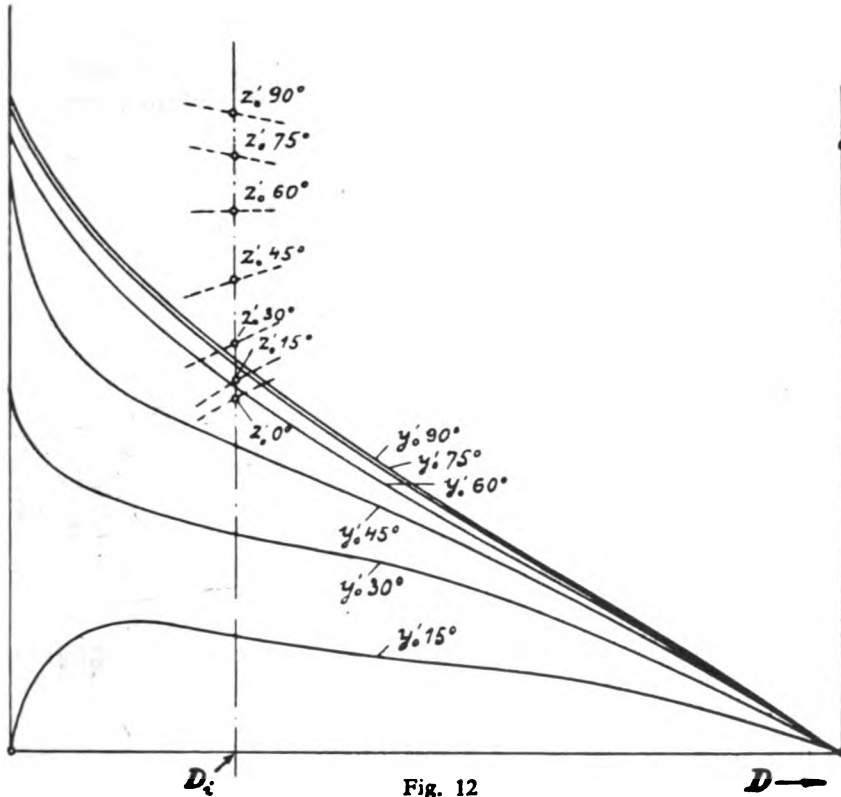


Fig. 12

z'_0 obtained in this way in Fig. 14 have to be laid off in Fig. 12 for the same displacement D_b , and so, after treating in the same way several displacements D_b , one can draw the lines z'_0 for the whole range (Fig. 11).

It is evident that in this case the starting point F_0 , i. e., the center of buoyancy for the upright position of the ship in Fig. 14 has to be known beforehand, Kempf's auxiliary construction determining only the points for the inclined position.

Method No. 2 — Having obtained the diagram in Fig. 12 by the instrument, steel tapes have to be readjusted so that they represent now the vertical moments of buttock-and-bow sections' areas.¹ The lines represent-

¹ Hence these lines should be calculated in the classical way (planimeter, tabulation methods, etc.).

ing these moments are shown in Fig. 10a where they are designated as $M_j(z')$ -lines (in the same figure the lines representing the areas of buttock-and-bow sections, i. e., A_j -lines, are shown). These lines are also monotonic and can be represented by steel tapes. Hence by moving in this case the water-line simulator g along the set c of bridges one can continually read — at the terminal of the first adder h (weight P) — the moment $M(z')$ of the displacement wherefrom the values z'_0 can be evaluated very easily.

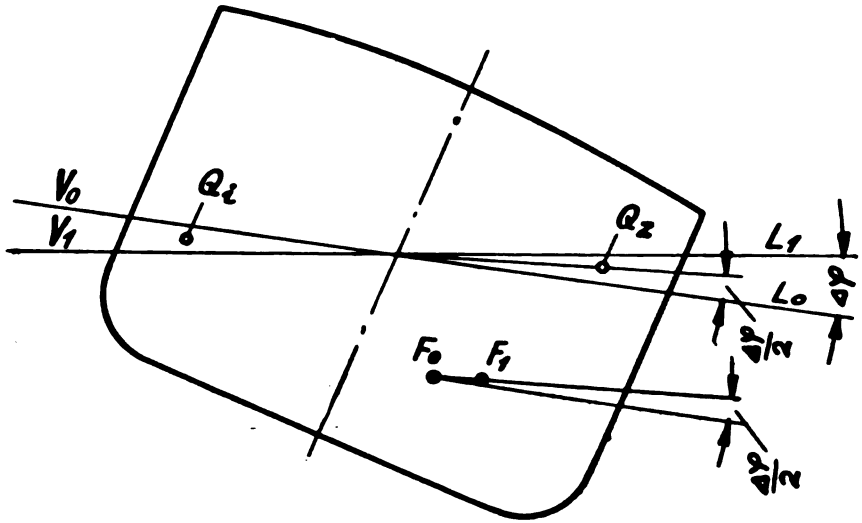


Fig. 13

Method No. 3 — After the diagram Fig. 12 has been obtained by the instrument, steel tapes are to be readjusted so that they represent the areas of water planes (A_z -lines). These curves, while integral lines, are also monotonic.

In this case the base-line 0 — 0 of the instrument corresponds to the axis O', z' so that, while the first adder h delivers the values of the displacement D , the second adder delivers the values of the moment $M(z')$ wherefrom the value z'_0 can easily be obtained.

Any of the three outlined methods for the evaluation of z'_0 by the instrument can be chosen.

The method No. 1 calls for only one setting of the instrument, but requires an auxiliary graphical construction and the data about the points F_0 for different displacements.

Most accurate results are obtained when combining the methods No. 1 and No. 3. Here the method No. 1 is used for the angles of inclination from $\varphi = 0^\circ$ up to $\varphi = 75^\circ$, and the method No. 3 for the angles $\varphi = 90^\circ$

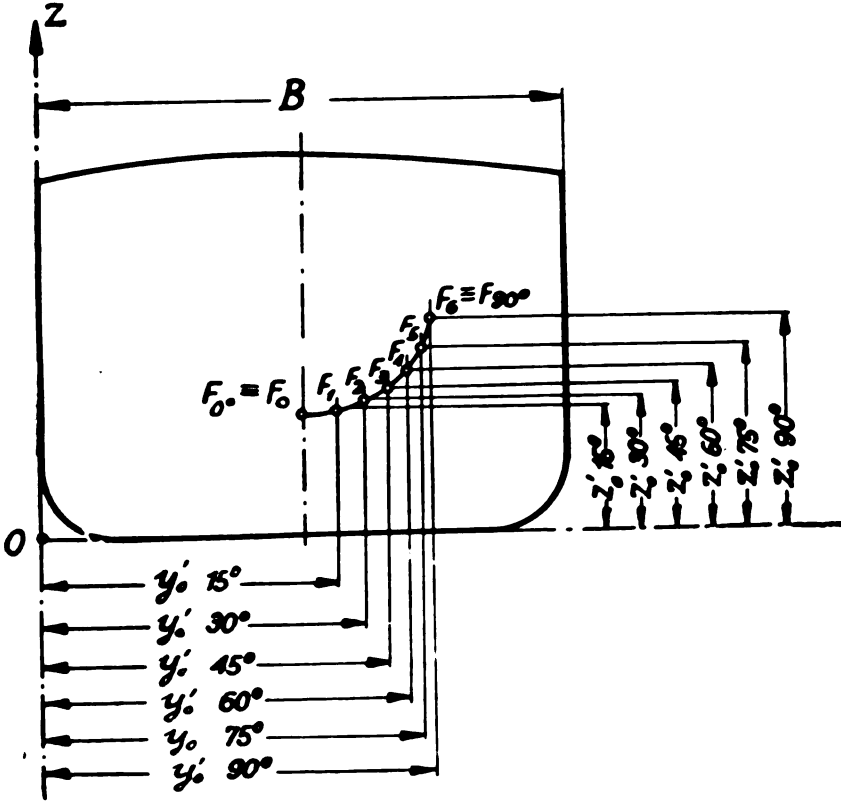


Fig. 14

down to $\varphi = 15^\circ$ (overlapping in the interval $\varphi = 15^\circ - 75^\circ$). When applying the method No. 3 to obtain z'_0 from the known values A_k in the interval $90^\circ - 15^\circ$ it is necessary to make use of Kempf's auxiliary construction analogous to the one previously. Hence with this combination 2 settings, 2 graphical constructions and the data concerning the starting points F_{0° and F_{90° for different displacements are needed.

In applying the method No. 2 two settings combined with a classical calculation of $M_j(z')$ -curves are required.

When as a result of the previous work a diagram as that shown in Fig. 11 is obtained, the diagram of „cross curves of stability“ or that of

„righting arms“ can be derived very easily. Besides, by certain formulae — which are well known from the theory — these diagrams can be extended beyond 90° inclination as well.

Thus the principles of work of the instrument in solving the fundamental problem No. 1, as well as one variant of the instrument itself have been set forth.

A detailed consideration of the sketch in Fig. 7 brings us to the conclusion that the movements delivered to the lower pulleys of the adder h consist of two different movements: the movement due to the sinking of the needle and the movement due to the departure of the carriage from the starting point of the bridge.

The latter movement should be prevented from being delivered to the adder. This can be achieved in many ways.

But, as the main cause of this complication is the unstable position of the carriages J against the adder h , the best way is to eliminate the relative movement of these two parts. In this case the water-line simulator should simply displace the vertical plates 37 (Fig. 36) to which the tapes 1 are fixed whereby carriages themselves would be stable.

Beside the presented instrument there are still many purely mechanical variants and sub-variants which could be developed, but it would be out of place to present all of them here. Many others, non-mechanical variants, are feasible, too. The mechanical one has been presented first only for the purpose of an easy introduction. For this reason we shall dwell on it a little longer.

b) *FUNDAMENTAL PROBLEM No. 2*

Before going into a broader discussion of the announced aspects of the instrumentation, let us turn our attention to the fundamental problem No. 2.

Within the fundamental problem No. 2 we have to evaluate the area, moment of area and moment of inertia of the arbitrary water planes. This is quite possible to achieve by our instrument. Namely, if the lines of the cross sections (because of the symmetry about the center plane only one half of each of these lines) are represented by steel tapes (the „base“ $0-0$ corresponding now to the axis $0, x$ — Fig. 1 — while the bridges relate to the x -stations and the needles read the y -values) and if the water-line simulator

is arbitrarily moved along the bridges, the output terminal of the adder h (Fig. 7) will continuously show the area (A_k), while that of the multiplier-adder h' will show the moment (about the axis $0, y$) of area of the momentary water plane [$M_k(x)$].

Here the work is done on the ship's longitudinal plan (steel tapes representing cross sections), the inclined water lines meaning thus the various trim positions of the ship. As it is well known, it is common to suppose that there is no heeling of the ship in this case.

In order to obtain by this procedure also the moment of inertia $J_k(x)$ (about the axis $0, y$) of the water planes in question, it is evident that another multiplier-adder h'' has to be introduced into the instrument. Now the movements of the needles have first to be multiplied by the lever-arm coefficients squared and only then added. This means that with mechanical variants (for example in Fig. 7) one transmission more has to be built in (either of the same ratio and in that case positioned after the first one — hence two in series which entails squaring — or of the ratio corresponding to the lever-arm coefficients squared and then independent), whilst with the electrical variants, which will be discussed at a later stage, a new current circuit has to be formed.

Hence in moving the water-line simulator g by the previous setup of the instrument the moment of inertia $J_k(x)$ can be read at the output terminal of the multiplier-adder h'' in addition to the fore-mentioned results read at the output terminals of the two earlier series.

Thus with this setup the characteristics of the water planes A_k , $M_k(x)$ and $J_k(x)$ (area, moment of area and moment of inertia for the transversal axis $0, y$) are obtained.

1) PRINCIPLE OF „REDUCED SHIP“

For finding the characteristic values of water planes for the longitudinal axis of water planes, two setups of the instrument are necessary.

First, we have to adjust steel tapes to represent the bow lines and that from the midship section to the bow. Hence the base $0 - 0$ of the instrument corresponds now to the axis $0', y'$ (Fig. 1), while the bridges correspond to the x' -stations and the needles read the x' -values (in adjusting the tapes the scales are chosen in such a way that the bridge is considerably longer than the greatest x' -value). In moving now the water-line simulator g along the bridges the values of the area $A_{k,y'}$, of the moment of area $M_k(y')$ and

of the moment of inertia $J_k(y')_f$ (the latter two values about the longitudinal x' -axis; index „f“ means „fore“ part of the ship) will be obtained.

Then a novel setup is done whereby the tapes represent the buttock lines from the midship section to the stern. The base 0 — 0 corresponds to the axis $0', y'$, while the readings at the output terminals indicate now the values of the area $A_{k,a}$, of the moment of area $M_k(y')_a$ and of the moment of inertia $J_k(y')_a$ („a“ = „after“ part of the ship).

Adding the respective values for both fore and after part, the values for the whole water line are obtained [$A_k, M_k(y'), J_k(y')$].

Of course, with the latter two setups the water-line simulator may be both horizontal (ship upright) and inclined. The latter case means the transversal inclination (healing), whereby — as usually supposed — there is no trimming.

Hence the latter two setups mean work on the ship's transversal plan whereby the water-plane characteristics about the longitudinal axis $0', x'$ are obtained, while the former setup meant work on the longitudinal plan whereby the plane characteristics about the transversal axis $0, y$ were obtained. The mentioned characteristics for these axes once being available, the positions of the centers of gravity of the planes, i. e., their leverages, as well as the moments of inertia about the axes through the C. G. are to be obtained very easily.

From these values and the values for displacement, which are obtained earlier, the values of metacentric radii will be evaluated very easily.

Thus the fundamental problem No. 2 as a whole is also solved. It includes all the problems of the kind [2; L or T; D or I].

It will be remarked that two setups were necessary when treating the fundamental problem No. 2 on the transversal plan. The reason for this is very simple: The carriage-and-needle device for reading the ordinates of functions is capable to do so only if the path of the carriage, i. e., the abscissa (the line perpendicular to the ordinate, hence to the value which is „read off“ by the needle) is a straight line. In the case mentioned where the x -values for the whole length of the ship had to be read off, such a straight line could be obtained only after cutting the ship into two parts and treating each of them separately. This was due to the lack of symmetry about the midship section. In the previous stage, when treating the fundamental problem No. 2 on the longitudinal plan (trimming), no cutting was required (and accordingly only one setting was necessary) and that just owing to the symmetry about the center plane.

In the fundamental problem No. 1 there was no need for cutting the ship into two parts longitudinally when working on the transversal plan and that simply because of the fact that only the integral curves were read off there. And since these curves had necessarily straight lines as abscissas, even though they related to the buttock and bow lines together (lines of vertical fore-and-aft sections as wholes), no cutting was necessary.

However, the need for cutting can be easily avoided in the fundamental problem No. 2, too. A good use can be made here of the fact that the translation of the x -values along their own directions does not affect the evaluation of $M_k(y')$ and $J_k(y')$. Hence instead of forming half-lengths, i. e., the buttock lines x'_a and bow lines x'_f separately, we can form the unique lengths $(x'_a + x'_f) = x$ whereby all $(x'_a + x'_f)$ -values (for all buttock and bow lines for all draft within one vertical fore-and-aft section and so for all these sections) start from one transversal plane. Indeed, a novel ship is brought forth thereby (let us call her „reduced ship“; her midship section is shifted to one end, while all the other sections have a smaller area or at most are equal to it), but there is no need for cutting now, and the inclination problems within the fundamental problem No. 2 can be solved by means of only one setting of function generators. (As a matter of course, the principle of the „reduced ship“ may be applied also to the water planes—horizontal ship's sections—when the calculation of z'_0 is in question).

II) SURVEY OF SETUPS

We see that on the whole 5 setups of the tapes are necessary to solve all the problems set out in the beginning. Three setups are called for by the problems which can be reduced to the fundamental problem No. 1, while further two are required by those which can be reduced to the fundamental problem No. 2. A survey of the setups is given in Table I.

Settings within the fundamental problem No. 2 differ from those of the fundamental problem No. 1 in that whereas the former settings (setups Nos. 4 & 5, Table I) can be established directly on the basis of the lines drawings, the latter ones (setups Nos. 1, 2 and 3) call for some preparatory work. Namely the very curves which are fed to the instrument within the fundamental problem No. 1 have first to be calculated by classical methods. However, this is the only preparatory calculation to be done and if performed with the aid of a planimeter, it will not take unduly long time. It should be remarked that only Bonjean curves (setup No. 1) have to be evaluated for all the longitudinal stations, whilst the further two series (setups

TABLE I

Problems are solved which reduce to the formula	Setup No.	Curves represented by function generators	Base 0-0 of the instrument corresponds to the axis	Bridges (abscissas) correspond to	Values (ordinates) delivered by function generators	Result read after multiplier-adder*		
						h	h'	h''
[1; L; any]	1	$A_i = f(x_i)$ Bonjean curves (areas of cross sections)	O, x	z_i	A_i	D	$M(x)$	—
[1; T; any]	2	$A_j = f(x_j)$ Areas of vertical fore-and-aft sections	O', y'	z'_j	A_j	D	$M(y')$	—
[1; T; any]	3	$M_j(x') = f(x')$ Vertical moments of vertical fore-and-aft sections	O', y'	z'_j	$M_j(x')$	M(x')	—	—
[2; L; any]	4	$A_i = y_i(x)$ Lines of cross sections	O, x	z_i	$y_i(x)$ $z = b_i$	A_{ik}	$M_{ik}(x)$	$J_k(x)$
[2; T; any]	5	$A_j = x_j(y')$ Lines of vertical fore-and-aft sections (buttock-and-bow lines — „reduced ship“)	O', y'	z'_j	$x_j(y')$ $z = b_j$	A_{jk}	$M_{jk}(y')$	$J_k(y')$

* See also the footnotes on pages 4 and 45.

Nos. 2 and 3), owing to the existing symmetry, have to be evaluated for only one half of the transversal stations.

The variants of the instrumentation which call for no pre-calculation whatsoever will be discussed at a later stage. The number of the necessary setups will be reduced, too (in the extreme case only one setup will be required). But for the time being, let us still dwell on the 5-setting variants.

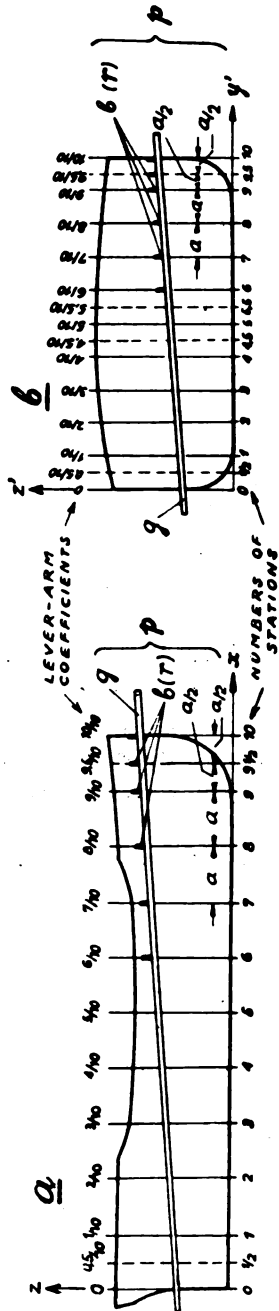
What ensues after the preparation, i. e., after the setup of function generators, is this: In one passage of the water-line simulator across the set of function generators — which positively does not take more than a couple of seconds — an infinite number of the positions of the water line in relation to the ship's hull is calculated.

The indications of the output terminals of the instrument can be recorded automatically on the basis of the position of the water line. There are many proved solutions for such devices, and we shall not enter into discussing them here.

III) SOME ADDITIONAL REMARKS

Let us turn now to some details of the 5-setting instrument.

The ordinates read off by the needles (or the products of these ordinates multiplied by the lever-arm coefficients) have merely been added so far. Besides, it has been assumed that the bridges have been disposed equidistantly. Hence the integration by the trapezoidal rule has been performed. But even here the coefficient 1/2 should be attached to the end ordinates, and no mere addition of the ordinates is allowed.



Figs. 15a and 15b

There are many ways to allow for these coefficients, but the simplest one is merely to adjust the steel tapes for these stations (bridges) not to the full values of the ordinates, but to the half-values. Thus the allowance for the coefficients $1/2$ is made beforehand and a mere addition of the ordinates, which is subsequently performed by the instrument, is quite correct.

Accordingly this leads us to a direct possibility of applying the other rules as well. In applying Simpson's first rule, Simpson's second rule, etc., the bridges (stations) should be designated by Simpson's multipliers, and care should be taken merely when adjusting their tapes (function generators in general) to set them in the scales corresponding to these multipliers.

Attention should be paid to dispose the „bridges“ proportionally at the same distances as are the sections of the real ship to which they relate and, as a matter of course, that must be done in the way which is implied by the rule of integration.

An example of feasible disposition is shown in Figs. 15a and 15b. This disposition (see also Fig. 8) is based on Simpson's rule of integration (below the sketches the numbers of stations are indicated and above the sketches the lever-arm coefficients). The pair of sketches corresponds to one instrument, due to the fact that one and the same disposition is applied with the instrument for both longitudinal and transversal plan.³

When on the longitudinal plan, „half-ordinates“ have to be introduced only in the end strips. But when on the transversal plan, half-ordinates have to be introduced also in the middle strips, because the curves treated on the transversal plan have a singular point there [see Fig. 10b where by $A_j = f(y')$ is designated (in function of y' , i. e., of the breadth of ship) the curve of the areas of the buttock-and-bow lines set by the line WL in Fig. 10a whose integral is to give displacement D ; by $M_j(x') = f(y')$ are designated the „ordinates“ of $M_j(x')$ -lines set by WL in Fig. 10a; integral of $M_j(x') = f(y')$ -line is to give the value of $M(x')$].

If necessary, „quarter“-ordinates and „quarter“-intervals could also be introduced. There is no hindrance for the application of Tchebyscheff's method either. The „bridges“ (function generators in general) should be merely disposed to suit the Tchebyscheff rule and that is all.

Table II presents three series of coefficients which are valid with the disposition of stations shown in Fig. 15a.

What matters with respect to the distances a_i is that function generators as such need not be disposed according to them. Only their movable parts (ele-

³ It is to be understood that with the real instrument not only the disposition, but also the actual distances a between the bridges are equal for both longitudinal and transversal plan. The latter is not effectuated with Figs. 15a and 15b in the interest of clearness only.

TABLE II

I	No. of station & lever-arm coefficient	0	1/2	1	2	3	4	5	6	7	8	9	9 1/2	10
II	Lever-arm coefficient squared	0	1/4	1	4	9	16	25	36	49	64	81	90 1/4	100
III	Simpson's integration coefficients (I - series)	1/8	2	1 1/2	4	2	4	2	4	2	4	1 1/2	1	1/8
IV	Product of I & III TLA - series,	0	1	1 1/2	8	6	16	10	24	14	32	18 1/2	19	9
V	Product of II & III TQA - series,	0	1	1 1/2	16	18	64	90	144	98	256	157 1/2	180 1/2	40

I - series = Simpson's series
 IIA - series = Simpson's series
 IIB - series = Simpson's series
 IIC - series = Simpson's series

ments commanding abscissas of function generators), i. e., parts which are actually actuated by the water-line simulator, must be disposed accordingly. Movable parts (abscissa-commanding elements) as such of function generators will be designated by r . Therefore in Figs. 15a and 15b the alternative designation r beside the designation b is introduced. With some function generators the subjection of the movable parts r to the distances a entails the same thing also for the function generators as such, but we shall encounter at a later stage the function generators which are able to subject to the distances a only their movable parts r .

2) PRINCIPLE OF MODEL INSTRUMENTS

Pick-up assembly p consists of two systems:

1) Set c of function generators b , or set of their movable parts r (parts of function generators by which abscissas of function generators are determined). This set represents the **model of the ship**.

2) Water-line simulator representing the **model of the ship environment**.

These two systems (two models) can be correlative and can form a new model, this time the **unified model of the ship in her environment** (hence our pick-up assembly p) only if some geometrical conditions (disposition of function generators b or that of the abscissa-commanding elements r , i. e., distances „ a “, Fig. 15) are fulfilled beside the normal computational conditions (adjustment of function generators and setup of coefficients).

Function generators are adjusted thereby to the contour lines of those ship sections of the real ship which are proportionally at the same distances as are the distances „ a “ of corresponding function generators b or of their abscissa-commanding elements r .

Hence the model of the ship in her environment has been the main point of the paper for the time being. This model differs substantially from the so-called „models of problems“, a term which can be met in normal text-books on analog computing techniques (for example „models of differential equations“ and the like which are set up in general-purpose analog computers). The latter ones are only computational models whereby the mutual relative geometrical disposition of computing units plays no part at all. What matters there is only the mathematically prescribed interconnection scheme of computing elements whereby the elements themselves might be scattered in the space quite arbitrarily. Contrary to this, our model is a computational and geometrical model at the same time, and that in such a

manner that its „geometrical component“, i. e., the disposition of function generators b or that of their elements r , plays a predominant part (computational characteristics, i. e., the adjustment of function generators and setup of coefficients, depend directly on the geometrical disposition of the elements r).

Instruments which are built on the basis of the model disposition of function generators b (or on that of their abscissa-commanding parts r only) will be called **model instruments**.

The choice of the number and disposition of function generators as well as that of the rule of integration depends on the accuracy to be achieved by these instruments.

3) MATHEMATICAL FOUNDATIONS OF THE INSTRUMENTATION

On the basis of the Table I and the other elucidations presented so far we can lay down the mathematical foundations of the instrumentation.

When treating the fundamental problem No. 1 on the longitudinal plan, the calculation of the following quantity is continuously performed by the instrument

$$\sum_{i=0}^{i=m} S_I \int_{z_i=a_i}^{z_i=b_i} y_i(z) \cdot z_i^r \cdot d z_i \Delta_i \quad \left(\begin{array}{l} i = 0 - m = x_i \\ r = 0, 1 \\ s = 0, 1 \end{array} \right) \quad (4)$$

When treating the fundamental problem No. 1 on the transversal plan the result

$$\sum_{j=0}^{j=n} S_I \int_{z_j=a_j}^{z_j=b_j} x_j(z) \cdot z_j^k \cdot d z_j \Delta_j \quad \left(\begin{array}{l} j = 0 - n = y'_j \\ k = 0, 1 \\ s = 0, 1 \end{array} \right) \quad (5)$$

is obtained in the same way.

The co-ordinates in these formulae refer to the two systems (origines O and O') in Fig. 1.

More explanations to these formulae are given in the first portion of the Table III.

Every one of the results D , $M(x)$ [or $M(y')$], $M(z)$ [= $M(z')$] requires one setup of the coefficients, i. e., the application of one of the multipliers-adders (determination of r) in combination with the corresponding

TABLE III

Fundamental problem No.	Setup of the coefficients No.	Coefficients & exponents		Plan of ship	Function generators are set to functions	Result*		Run of the instrument No.	
		Multiplier-adder	r			s			
1	1	h I-series (c^I_i)	0	0	Longitudinal	$y_i(z)$	D	1	
					Transversal	$x_j(z)$		1'	
	2	h' IIA-series (c^{II}_i)	1	0	Longitudinal	$y_i(z)$	$M(x)$	2	
					Transversal	$x_j(z)$		2'	
	3	1	h I-series (c^I_i)	0	1	Longitudinal	$y_i(z)$	$M(z)$	3
						Transversal	$x_j(z)$		3'
2	1	h I-series (c^I_i)	0	0	Longitudinal	$y_i(z)$	A_k	4	
					Transversal	$x_j(z)$		4'	
	2	h' IIA-series (c^{II}_i)	1	0	Longitudinal	$y_i(z)$	$M_k(x)$	5	
					Transversal	$x_j(z)$		5'	
4	2	h'' IIQA-series (c^{III}_i)	2	0	Longitudinal	$y_i(z)$	$J_k(x)$	6	
					Transversal	$x_j(z)$		6'	

* See also footnote on page 4

value of the exponent s . The runs of the instrument are related within the fundamental problem No. 1 only to the number of the coefficient setup, but are more closely specified according to the functions to which the function generators are set, i. e., according to the plan of ship to which the problem in hand is related.

The designations I, ILA and IQA mean respectively integration coefficients (e. g. Simpson's multipliers), integration coefficients multiplied by linear lever-arms and integration coefficients multiplied by lever-arms squared (quadratic lever-arms). (See also Table II).

Ξ_{sI} = is the operator meaning the integral sum according to Simpson's first rule of integration. It is best conceived by presenting (4) in expanded form:

$$\begin{aligned} & \sum_{i=0}^{i=m} S_I \left(i^r \int_0^{b_i} y_i(z) \cdot z_i^s \cdot dz_i \right) \Delta_i = \\ & = \left[0.5 \cdot (0)^r \int_0^{b_0} y_0(z) \cdot z_0^s \cdot dz_0 + 2 \cdot (1.5)^r \int_0^{b_{0.5}} y_{0.5}(z) \cdot z_{0.5}^s \cdot dz_{0.5} + \right. \\ & + 1.5 \cdot (1)^r \int_0^{b_1} y_1(z) \cdot z_1^s \cdot dz_1 + 4(2)^r \int_0^{b_2} y_2(z) \cdot z_2^s \cdot dz_2 + \\ & + 2(3)^r \int_0^{b_3} y_3(z) \cdot z_3^s \cdot dz_3 + \dots + 1.5(m-1)^r \int_0^{b_{m-1}} y_{m-1}(z) \cdot z_{m-1}^s \cdot dz_{m-1} + \\ & \left. + 2(m-0.5)^r \int_0^{b_{m-0.5}} y_{m-0.5}(z) \cdot z_{m-0.5}^s \cdot dz_{m-0.5} + 0.5 m^r \int_0^{b_m} y_m(z) \cdot z_m^s \cdot dz_m \right] \Delta_i. \end{aligned} \quad (6)$$

Hence, this is the expanded form of (4) for the case of the longitudinal division into m elementary intervals whereby the end strips are also divided into half-intervals. The analogous relation would hold for the expanded form of (5). In this case, as shown earlier, the middle intervals should also be divided into half-intervals.

It is easy to understand what form would take the series (6) if the instrument were suited to Ξ_T (= trapezoidal rule of integration), Ξ_{SII} (= second Simpson's rule), Ξ_{TH} (= Thompson's rule), Ξ_{TCH} (= Tchebycheff's rule), etc.

When treating the fundamental problem No. 2 on the longitudinal plan the calculation of the following quantity is continuously performed:

$$\cdot \int_{i=0}^{i=m} i^r \cdot y_i(x)_{z=b_i} \quad \left(\begin{array}{l} i = 0 - m \equiv x \\ r = 0, 1, 2 \end{array} \right) \quad (7)$$

When treating the fundamental problem No. 2 on the transversal plan the analogous quantity

$$\int_{j=0}^{j=n} j^r \cdot x_j(z)_{z=b_j} \quad \left(\begin{array}{l} j = 0 - n \equiv y' \\ r = 0, 1, 2 \end{array} \right) \quad (8)$$

is obtained in the same manner.

Terms $y_i(x)_{z=b_i}$ mean half-breadth of ship of the i -th cross section and at the draft $z = b_i$. Analogous explanation is valid for the terms $x_j(z)_{z=b_j}$, too. More explanations to the formulae (7) and (8) are given in the second portion of the Table III.

The arbitrary moving of the water-line simulator of the instrument which simulates the natural water line and whose relation towards the ship is thus kept varying) corresponds to an arbitrary and continuous variation of the upper limits b_i and b_j of all the integrals ($i = 0 - m, j = 0 - n$) in the relations (4) and (5) and also of all the function arguments b_i and b_j in the relations (7) and (8). This results in an automatic evaluation of all the results covered by the fundamental problems Nos. 1 and 2 whereby the water-line simulator is moved quite arbitrarily and, if necessary, also continuously.

It is seen from the formulae (4) and (5) that two successive integrations are performed within the fundamental problem No. 1. The first integration is indicated by the symbol $\int_x () dz$ (the terms $\int_x y_i(x) x_i^r dz_i$ and

$\int_x x_j(z) (z)^r dz_j$) while the second one is represented by the symbol $\Xi () \Delta_{i,j}$.

The first integration relates to the ship's sections directly, whilst the second one means integration versus either the length or the breadth of the ship.

The first integration is *exact* in principle whereas the second one, being performed by means of the trapezoidal, Simpson's, Tchebyscheff's rules of integration, etc., is only *approximative*.

Our instrument is not as yet capable of performing both these integrations. It treats only the second integration $\Xi () \Delta_{i,j}$ while the first

integration $\int (\) dz$ must be performed by classical means (planimeter or the like). The results of this integration are fed to the instrument as individual settings of the function generators.

Hence our 5-setting variant of the instrument is an „one-integration“ variant, in contradistinction to the two-integration variants which would be a desideratum for our instruments.

The 5-setting variant of the ship analyzer described in the early part of this discussion is only one feasible variant among many others. Namely, it is evident that by the variation of the function generators and multiplier-adders a large number of one-integration instruments can be constructed. All these instruments are represented by block diagram in Fig. 54.

4) ELECTRICAL INSTRUMENTS

The adjusting of the steel tapes in scales corresponding to the integration coefficients is a rather unhandy solution to allow for these coefficients. There are many better solutions to be applied. Approaching them we are actually going to encroach upon the electrical variants of the instrumentation.

Instead of mechanical adders presented in Figs. 6 and 7 many schemes of electrical ones can be used. In Figs. 16 and 17 two schemes based on the addition of tensions are presented. The latter of these schemes is applied in Fig. 18 where we see the previously mentioned carriages 3 and needles 4. In Fig. 19 the scheme is presented which is based on the addition of currents.³ Potentiometers 28 are tension-forming potentiometers; the currents formed after passing through resistors 30 (resistances of resistors 30 are strictly equal) are directly added.

If the voltage-addition scheme in Fig. 17 is to be a mere adder, the specific linear resistances of all potentiometers 28 have to be equal. If the scheme is to be a multiplier-adder, then the specific linear resistances of the tension-forming potentiometers 28 have to be proportional to the multiplying coefficients of the three significant series of coefficients (the series I, IIA and IQA, see Table II). Hence, in this case three series of tension-forming potentiometers are necessary.⁴ Thus, in lieu of Fig. 17 we should

³ To differentiate between *potentiometers* and *resistors*, potentiometers are designated by a zigzag line in our schemes while resistors are represented by a long rectangle.

⁴ To obtain a multiplier-adder in the case of multi-source voltage-addition schemes (schemes with individual tension sources for each of the potentiometers 28, see Fig. 16) the resistances of the tension-forming potentiometers 28 can be equal with the tensions of the sources varying proportionally to the multiplying coefficients.

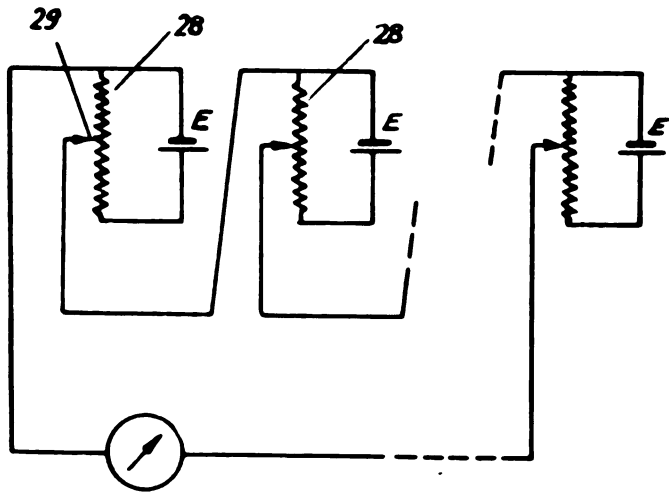


Fig. 16

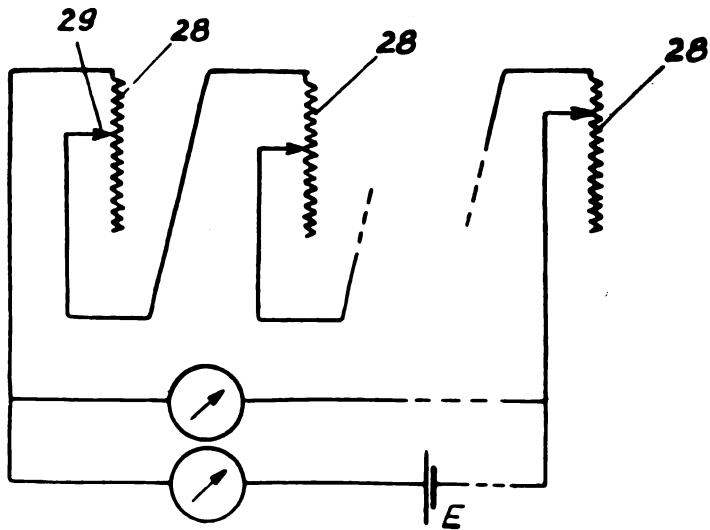


Fig. 17

have Fig. 17a where the switch 31 includes only one series of potentiometers at a time (or three independent measuring circuits could be attached to one series of the three-wiper needles so that all the three series of potentiometers are active at a time). If the current-addition scheme in Fig. 19 is to

represent a multiplier-adder rather than a simple adder, the reciprocals of the resistances ρ_i of the resistors 30 must be proportional to the multiplying coefficients required.

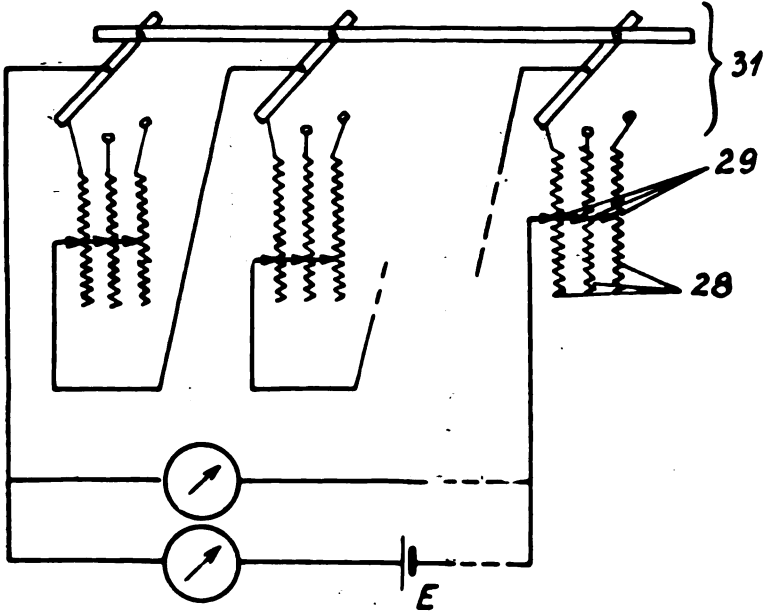


Fig. 17a

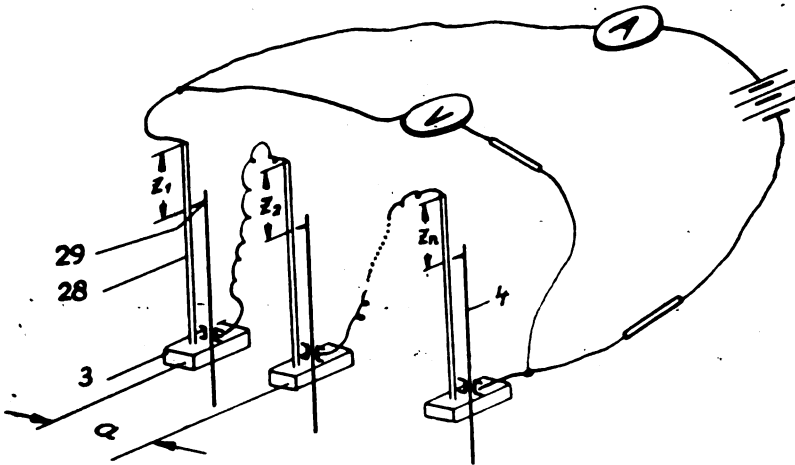


Fig. 18

In general, many combinations of the electrical schemes are possible. Fig. 20 presents one of them which derives from Fig. 19 (addition of cur-

rents). There is only one series of the resistors 30, but each of them has three taps and the switch 31 provides for the inclusion of only one series of coefficients at a time. Besides, the end summation is performed by the amplifier *A* (Refs. [8], [9], [13]).

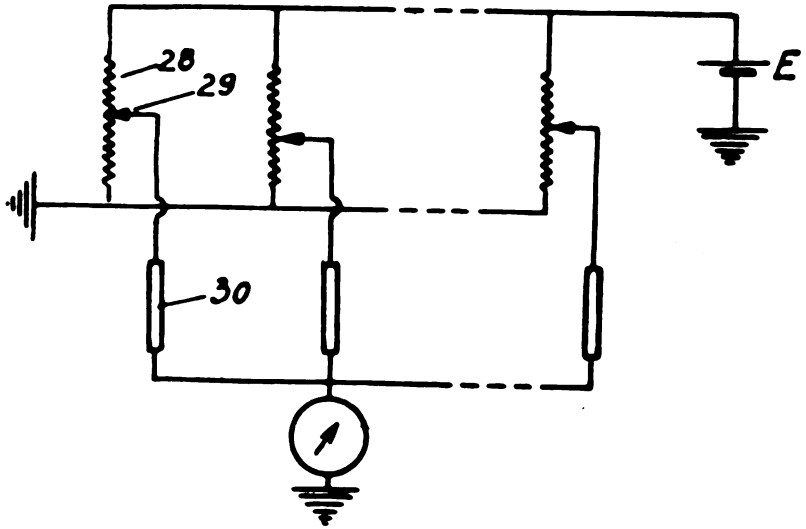


Fig. 19

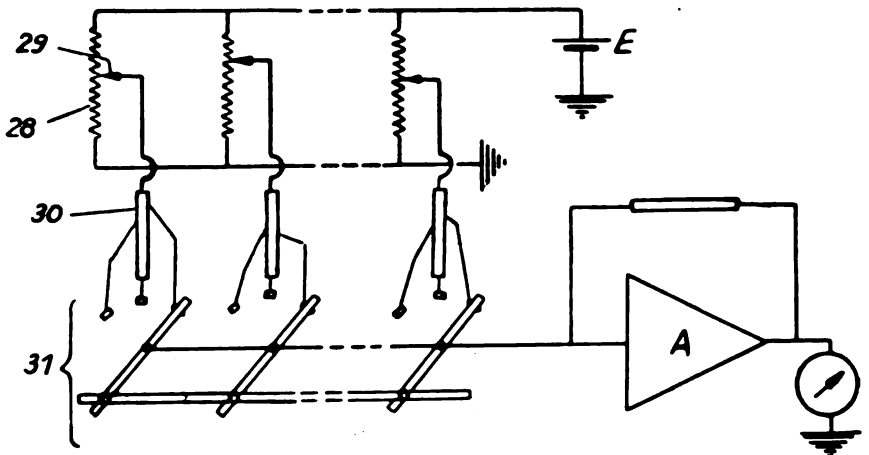


Fig. 20

It is beyond any doubt that electrical summation (and multiplication) could be developed in an analogous way also on the basis of capacitances as well as on that of inductance.

a) FUNCTION GENERATORS

So far electrical solutions have been applied only to the multiplying-adding tract of the instruments. But no difficulty is presented for them to be applied in the pick-up assembly as well.

The following method may be used for this purpose: The curve to be set to the instrument is first drawn on a piece of paper 72 laid down on the plate 37 (Fig. 21). Wire 73 (0.4—0.6 mm or so) is then put on the graph of the curve and is temporarily held by means of small split pins. Then the wire is covered with a layer of special cement which, when dried, fastens the wire to the paper 72 (split pins are removed in good time). Then the upper surface of the wire 73 is laid bare by abrasive cloth.

Plate 37 is movable in its traversings 46 built in the instrument. Linear potentiometer 28 is mounted against these traversings (Figs. 22 and 23) and is lightly pressed to the wire 73. Wires 73 of all the plates are interconnected and the set of plates is then actuated by the water-line simulator g whereby the pick-up unit p of the instrument is established.

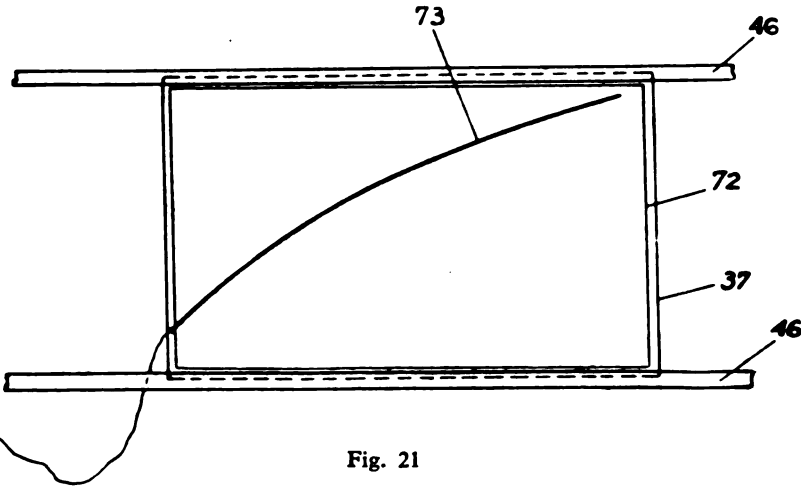


Fig. 21

It is evident that the scheme presented by Fig. 19 has been applied in Fig. 23 (resistors 30 are tapped). The other schemes can be applied, too. The potentiometer 28 which leans against the wire 73 is evidently tension-forming potentiometer whereby the wire 73 is used simply in lieu of the normal wiper 29.⁵

⁵ The difference is formal. The wiper moves along the potentiometer, whilst the plate 37, bearing wire 73, is moved perpendicularly to it.

The technique of cementing the wire 73 to the paper 72 and other features in connection with this method of function generation have well been developed by some computers of the firm Reeves Instrument Corp. in U.S.A.

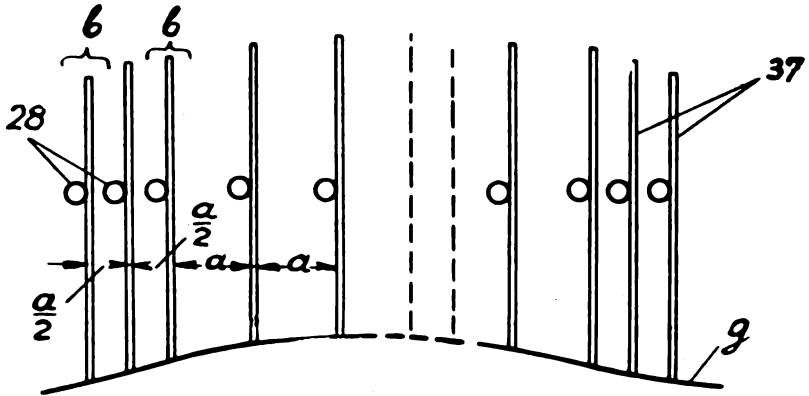


Fig. 22

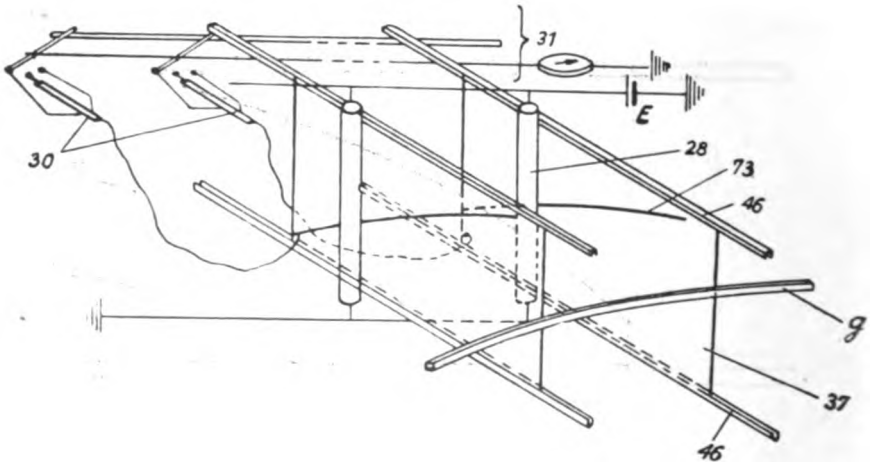


Fig. 23

Plates 37 are disposed in full accordance with the rules of the model of ships in her environment (distances „ a “, „ $a/2$ “, ... and the values of coefficients determined thereby) and they are actuated directly by the water-line simulator g (Fig. 23).

The standard *tapped potentiometers* (Refs. [8], [9], [13]; Fig. 24) can be used here as function generators, too. In our parlance they should be designated as the *tension-forming potentiometers* 28. Constructionally

they are made as one-turn or multi-turn (helicoïdal) potentiometers. Therefore a shaft has to be revolved in order to get their wiper to slide along the potentiometer. In this case tapped potentiometers can be disposed quite arbitrarily and only the ends of the cables actuating these shafts (these ends being effectuated as abscissa-commanding elements r) have to be disposed in accordance with the model rules.

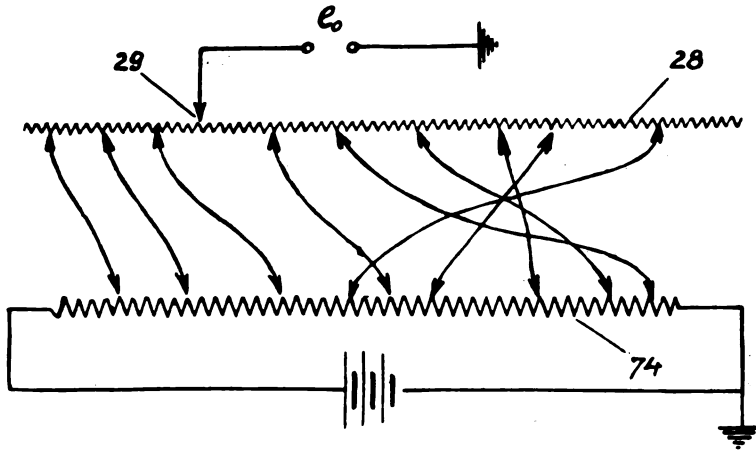


Fig. 24

The same is valid for the application of *diode function generators*: The generators themselves can be disposed quite arbitrarily and only the elements b commanding the independent variable have to be in accordance with the model rules.

There is a number of function generators, more or less standard and original, which can be applied here in addition to the ones above-mentioned. But, no matter which type of function generators is used, the disposition of function generators (or that of their abscissa-commanding elements r only) is to be effectuated in accordance with the rules of the model. (Some function generators are described in more detail in Appendix I).

C) TWO-INTEGRATION INSTRUMENTS

a) INDIVIDUAL INTEGRATION

1) I. I. MECHANICAL AND ELECTRICAL INSTRUMENTS

For obtaining two-integration variant of the instrumentation, integrating elements should be built in the instrument.

The most common mechanical integrator is the so-called friction-wheel integrator shown in Fig. 25 (Ref. [4]). The first input parameter ds (independent variable, abscissa) is fed to the integrator as the rotation of a shaft 47 which bears a plane disk 48. The second input parameter (function u , ordinate) is given by the needle 4 which transmits its vertical movement to the friction wheel 49; this wheel is keyed on the shaft 50 with the freedom for axial motion. The distance from the contact point between the friction wheel and the disk to the axis of the disk shaft 47 is the second input parameter u . The output parameter is represented by the angle of rotation of the shaft 50 which is a measure of $\int u \cdot ds$.

If two such integrators with disks 48 and 63 are connected in series (Figs. 26 and 27), then the rotation of the shaft 51 of the second friction wheel 52 gives the measure of $\int u \cdot s \cdot ds$. The axial motion of the wheel 52 is governed by the input shaft 47 (Fig. 27, i. e., the elements 57, 58, 59, 60). Hence the motions of the racks 53 and 54 give the measure of $\int u \cdot ds$ and $\int u \cdot s \cdot ds$ respectively.⁶

Thus it remains only to mount such a set of two integrators on the carriage 3 (Fig. 27) and to mesh the gear 55 of the input shaft 47 with the rack 56 which is fixed to the stable bridge 2 and so to obtain a very efficient two-integration variant of our instrumentation.⁷

⁶ With the second integrator the disk input is $d(\int u ds)$ whilst the needle (shaft 51) input is s , so that the output is $\int s [d(\int u ds)] = \int u s ds$.

⁷ If the carriage 3 is fixed and serves only as a guiding for the vertical movement of the needle 4 whereby the water-line simulator actuates directly the plate 37 bearing the tape 1 (see Fig. 36), then the gear 55 is to be meshed with the plate 37 (or with the water-line simulator g directly) rather than with the bridge 2.

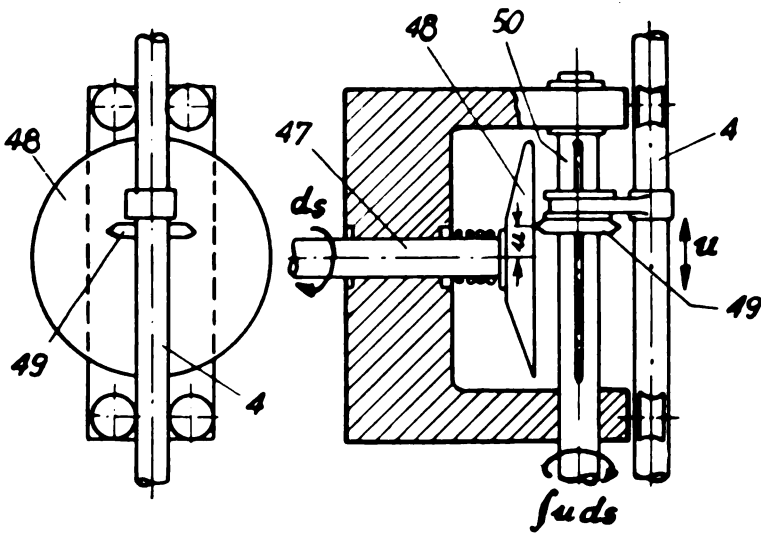


Fig. 25

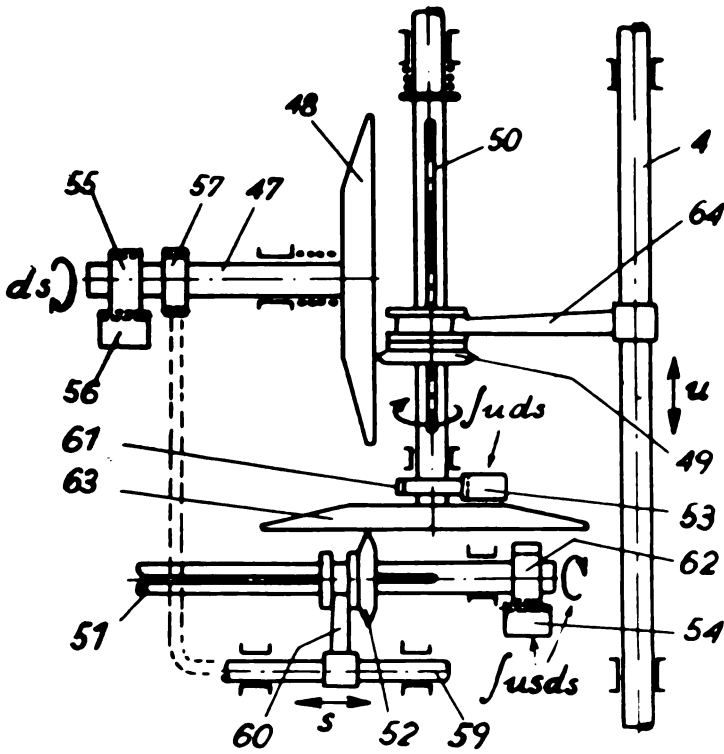


Fig. 26

If the steel tapes 1 represent the cross sections of the ship's hull so that the bridges 2 correspond to the z -axis (Fig. 28) whereby the needles 4 read off the y -values ($z = s, y = u$), then the racks 53 and 54 will give the

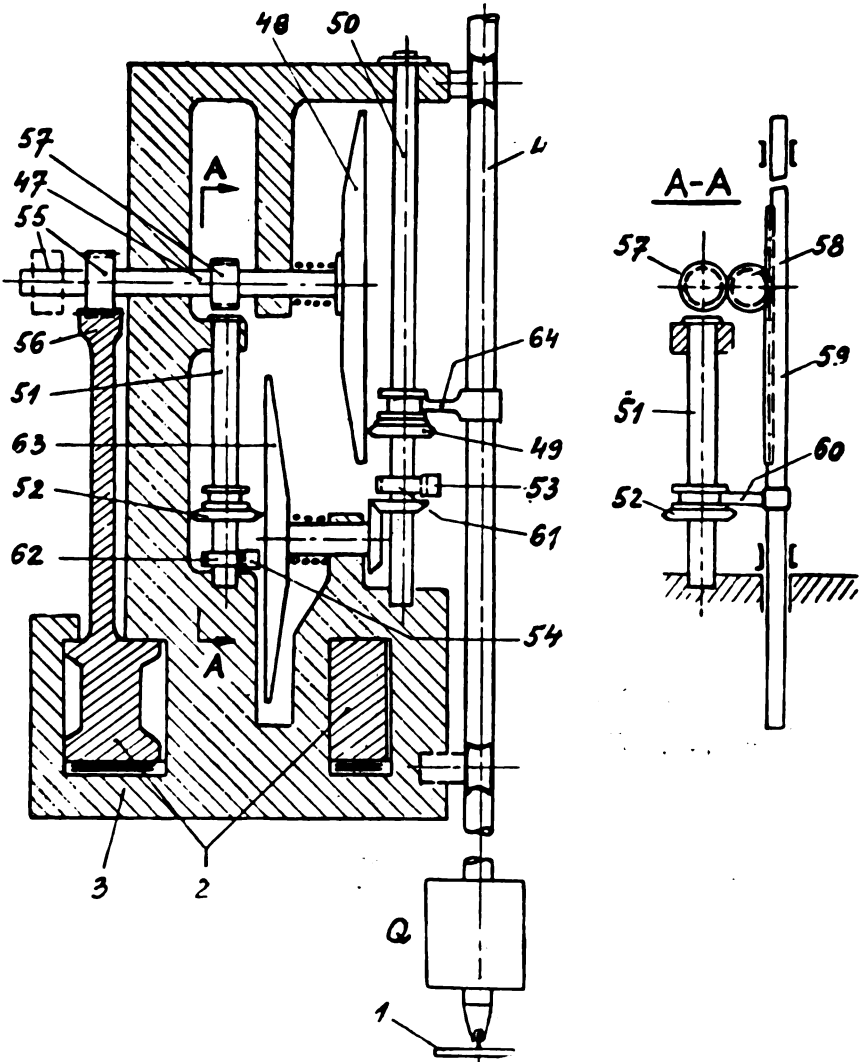


Fig. 27

measure of the area A_t and of the moment of area $M_t(z)$ about the y -axis of the corresponding cross section. If the rack 53 is connected to the h and h'

multiplier-adders and the rack 54 to the h multiplier-adder, then these circuits will give respectively a direct measure for the displacement D , longitudinal moment of displacement $M(x)$ and vertical moment of displacement $M(z)$.

Hence such was the procedure within the fundamental problem No. 1 and that on the longitudinal plan (trimming). The procedure on the transversal plan (heeling) is quite analogous: The function generators have simply to represent the buttock-and-bow lines („reduced ship“) instead of the cross-section lines. The output results in this case are respectively the displacement D , the transversal moment of displacement $M(y')$ and the vertical moment of displacement $M(x')$.

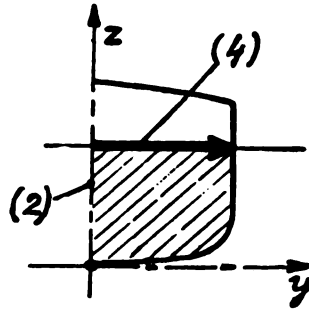


Fig. 28

When treating the fundamental problem No. 2 the whole set of integrators has to be disengaged (gear 55 in „idle“ position), and the potentiometers

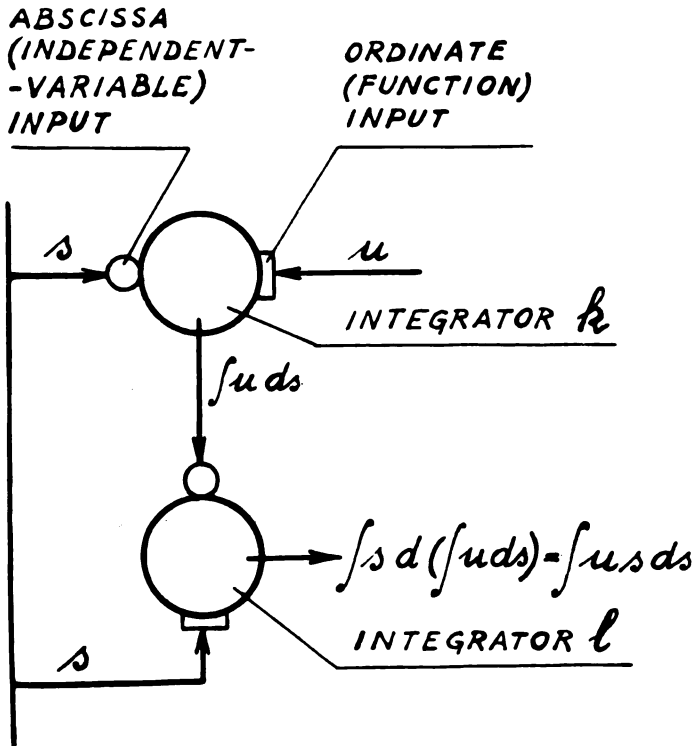


Fig. 29

(in general multiplier-adders h , h' and h'') have to be connected directly to the needles 4.

Of course, not only potentiometer adders and friction-wheel integrators can be applied here, but also other types of computing elements.

In principle a pair of integrators of any type (excluding „time-based“ integrators which will be treated at a later stage) which are connected as shown in Fig. 29 are applicable here. It is essential that the data received by the first integrator k be the ordinates of the functions which are received at the ordinate input of the integrators and the movements along the bridge (the displacement z of the abscissa-commanding elements r) which are received at the abscissa input. The data by which the second integrator has to be fed are the result of the first integrator k which is to be received at the abscissa input and the movement z along the bridge (abscissa in general) which is to be received at the ordinate input of the integrator.

As we have just seen, in the case of this variant only 2 setups are required for the complete elaboration of both fundamental problems. These are the setups Nos. 4 and 5 from the Table I, hence those for which no pre-calculation is necessary. The reason for this is quite clear: We have a *two-integration instrument* now which evidently needs no calculating preparation.

Hence this variant is very efficient in application, which — indeed — entails its being rather complicated from the manufacturing point of view since every function generator must have a pair of integrators. As the integration is carried out „individually“ on every bridge, this variant will be spoken of as the individual-integration variant, i. e., I. I. variant. Block diagrams for the I. I. instruments in general are represented by Fig. 55.

2) I. I. OPTICAL INSTRUMENTS

Let us draw our attention to a quite novel variant of our instruments now. Broadly speaking only mechanical and electrical variants have been considered hitherto, so that optical variant, which we are going to approach now, appears as quite a new element.

The optical variant is based on a suitable application of Gray's photo-electric integrator or the cinema integraph as it is sometimes called (References [1], [2], [5]).

In this integrator (Fig. 30) light from a line source 77, which is parallel to the u -axis, is made to pass through the apertures (let us call them „functions“) in two cardboards 78 and 79 (let us call them „function cardboards“).

The scales of the apertures and distance between cardboards are adopted so that the ordinates of the two apertures (functions) at the same value of the abscissa s are coplanar with the light source 77. The light let through the apertures is collected by the lens 80 and focussed on the photocell 81. The

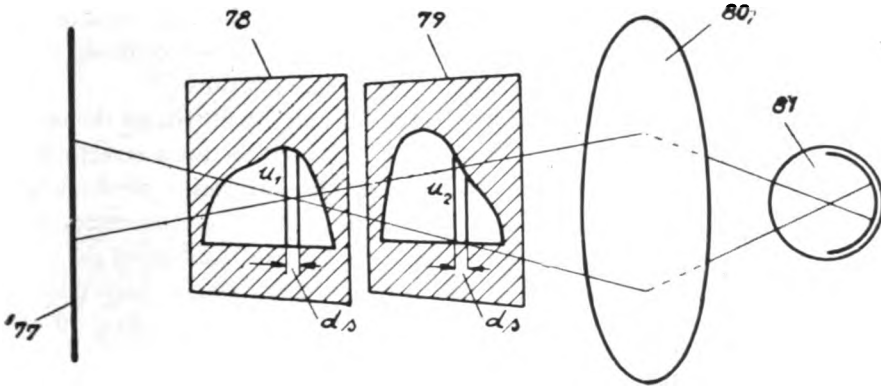


Fig. 30

photocell current is a measure of the total light flux through the two functions (apertures).

As the light flux through an element $du_1 \cdot ds$ of the first function and the corresponding strip $u_2(s) \cdot ds$ of the second function is $u_2(s) \cdot du_1 \cdot ds$, the total flux through both ds -strips will be $u_1(s) \cdot u_2(s) \cdot ds$, while the total flux through the two apertures generally will be

$$\int u_1(s) \cdot u_2(s) \cdot ds \quad (9)$$

Hence the photocell current is a measure of this integral and all the integrals of this kind can be treated by Gray's integrator.

An outstanding feature of this integrator is that the integration for the whole range of abscissa is performed *instantaneously* and not by successive addition of the contributions collected when passing along the abscissa, this being a common feature of the majority of integrators.⁹

In the case of the fundamental problem No. 2 the reading off the „ordinates“ only (the lines of intersection of water planes and ship's sections)

⁹ A modification to Gray's original integrator is presented in Appendix II. The modified integrator, though optical, is capable of performing also an accumulating (non-instantaneous) integration.

is necessary whereas the reading off (integration) the section's area is not required. In this case two methods of using Gray's basic integrator are possible:

Method No. 1) The light source has to be masked or provided with some mirror or the like, so that the light is cast only in one radial plane. Only one function cardboard is placed here between the light source and the lens. Hence the light plane will cut the function in one ordinate only, and the photocell current will be a measure of this ordinate.

Method No. 2) The light source has to beam normally (in all the radial planes), but close to the function cardboard there will be set a screen cardboard with a line aperture (slot). In this way the integration of the intersection line (area of aperture covered by slot) is actually performed, but, as the breadth of the slot is small enough and as the breadths of the slots of all the screen cardboards (in all the possible dark cameras incorporated into one instrument) are strictly equal, practically only the reading off the lengths of the ordinates is performed.

It is evident that with the method No. 1 either the function cardboards or the light sources themselves have to be movable for enabling the ordinate to be moved across the section, whilst with the method No. 2 both of them may be fixed due to the screen cardboards which are movable for this purpose (the screen cardboards may be fixed, too, but the function cardboards have to be movable then).

If the fundamental problem No. 1 is in question where the reading off (integration) of the section's area is necessary, then Gray's integrator is used in a normal way. Most frequently only one function cardboard is necessary in one dark camera in this case, and the screen cardboards, which are simple (not slotted) now, simulate the water line directly.

Hence if we divide a longer case into as many separate dark cameras ⁸² (Fig. 31) as we have ship's sections,⁹ if in each camera one Gray's integrating unit is situated with cardboard apertures representing ship's cross sections, and if the set of screen cardboards is somehow movable from outside the case (e. g. screen cardboards are suspended on a bar which represents the water line, that is the water-line simulator), then the sum of the photocell currents will be a measure either of the area of the water plane (slotted screen cardboard, fundamental problem No. 2) or that of the displacement of ship (simple screen cardboard, fundamental problem No. 1).

⁹ Such an instrument would, evidently, be rather bulky and inappropriate. It is such because of the „individual-integration“ scheme which is applied here. Nevertheless, its presentation is made because of the fact that the considerations are also valid for the so-called concentrated-integration optical instrument which is quite adequate and will be presented at a later stage.

The work on the ship's transversal plan is completely analogous to this, the only difference being that the instrument has to be „charged“ with a new set of function cardboards with the apertures representing now the buttock-and-bow sections instead of the cross sections.

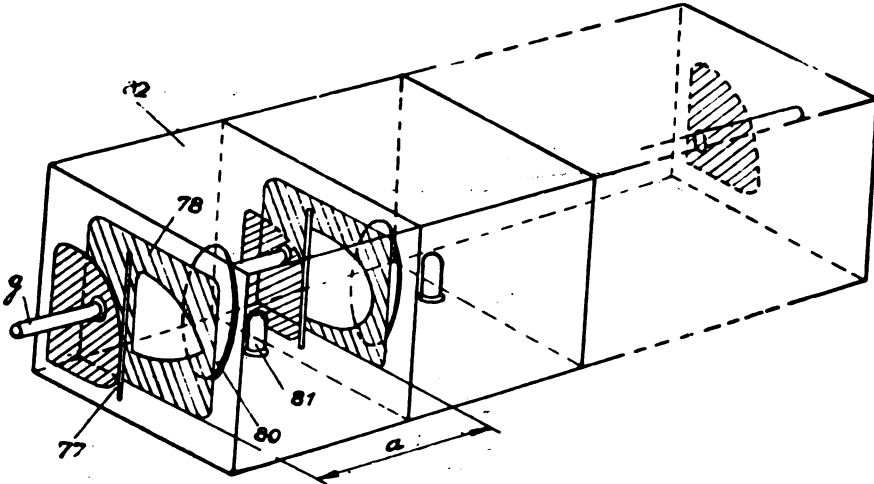


Fig. 31

Other elements [$M_k(x)$, $M_k(y')$, $J_k(x)$, $J_k(y')$, $M(x)$, $M(y')$] can be obtained in the same way, but, before addition, photocell currents have to be treated by the ILA- and IQA- series coefficients rather than by I-series ones.

For the completion of the fundamental problem No. 1 the values of $M(x)$ or $M(x')$ *) should be obtained in addition to the above-mentioned values. To avoid the evaluation of the curves of the vertical moments of the buttock-and-bow section areas (which was necessary with the 5-setting, i. e., one-integration variants), the following can be done;

For vertical moment of area under any curve $u = f(s)$ (Fig. 32) we have in general

$$M(u) = \int u \cdot ds \cdot \frac{u}{2} = \frac{1}{2} \int f^2(s) \cdot ds = \frac{1}{2} \int f(s) \cdot f(s) \cdot ds \quad (10)$$

This integral can very easily be solved by Gray's integrator. A simple comparison of the terms (9) and (10) leads to that conclusion.

*) $M(x) = M(x')$, since $|x| = |x'|$. Nevertheless, $M(x)$ implies work on the longitudinal plan of ship, whereas $M(x')$ relates to the transversal plan. If there is no doubt as to the plan of ship in question, this distinction is often neglected.

As buttock-and-bow sections are actually (Fig. 1) the curves $z' = f(x)$, the vertical moment of area of one buttock-and-bow section is

$$M_j(z') = \frac{1}{2} \int f^2(x) \cdot dx = \frac{1}{2} \int f(x) \cdot f(x) \cdot dx \quad (11)$$

Hence we have simply to put into the instrument two sets of function cardboards 78 and 79 whereby both sets represent the same curves, i. e.,

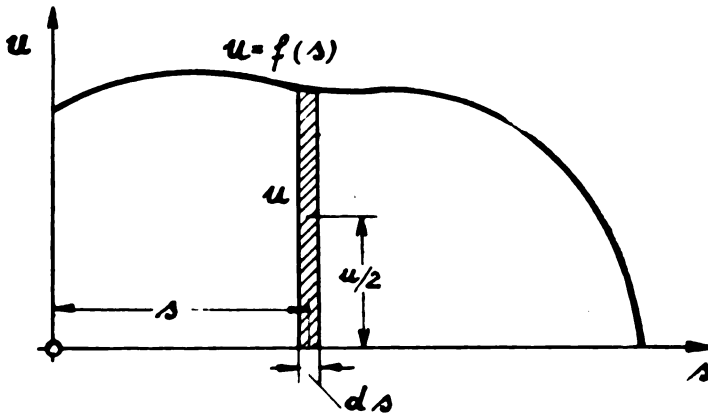


Fig. 32

the buttock-and-bow sections, hence the curves which do not demand any pre-evaluation.

Thus the one-integrator unit will read the momentary value of the moment of area $M_j(z')$ of the corresponding buttock-and-bow section, while the whole set of integrator units will show the value of the vertical moment of the displacement $M(z') = \int M_j(z') \cdot dy'$ for the momentary water plane.

However, as the condition of coplanarity of the two function cardboards 78 and 79 with the light source for the same abscissas has to be fulfilled, the two sets of cardboards (apertures) can not be quite equal. The first of them is normal, while the second must be extended (Fig. 33) proportionally to the ratio n/m (m and n are the distances from the light source).

But neither one nor the other of the methods just outlined for the completion of the fundamental problem No. 1 ought to be used with this instrument.

The final purpose here is to obtain the so-called „righting-arm“ curves, i. e., the value GZ (Fig. 34). If the values y'_{φ} and z'_{φ} [beside the values z'_0 (KF_0), $B/2$ and KG which are invariable when heeling the ship] are available for an angle of inclination φ , the value GZ is directly determined. Hence

the values y'_{op} and z'_{op} (Fig. 11) were the steps towards the determination of the value GZ until now. (Indeed, this method involving the y'_{op} and z'_{op} -values offers a series of advantages, especially with regard to a good checking of the results — see Ref. [17]). But with the optical instrument the possibility of a direct evaluation of the very GZ-values is necessarily offered.

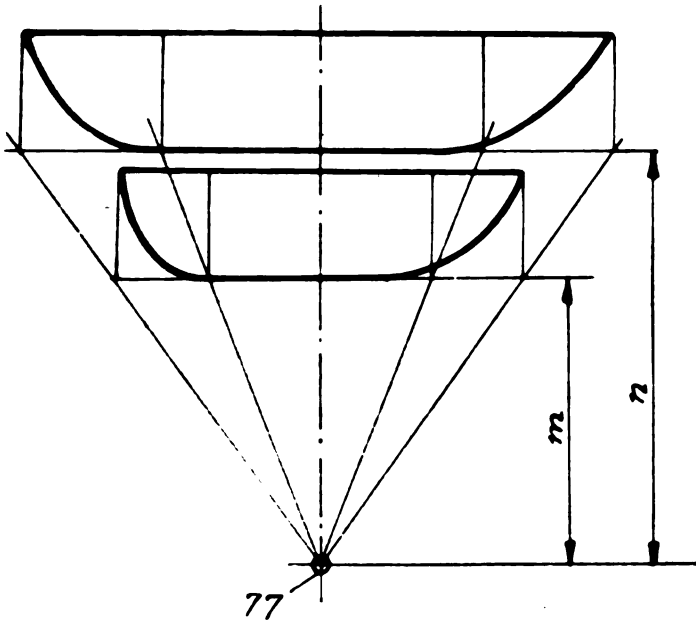


Fig. 33

For the evaluation of the GZ-value the data about the area and the moment of area about the axis 0—0 perpendicular to the water line WL are required (Fig. 34). This is analogous to the evaluation of the area A and the moment $M(s)$ of area under any curve $u = f(s)$ about the axis u in Fig. 32. For this moment we have:

$$M(s) = \int u \cdot s \cdot ds = \int f(s) \cdot s \cdot ds \quad (12)$$

and as this integral can be solved very easily by the normal method of use of Gray's integrator, we can do the following:

If the first set of function cardboards 78 with the functions (apertures) representing the ship's cross sections $z' = f(y')$ and the second set 79 with the functions representing the functions $z' = y'$ are put in the in-

strument, and then if the screen cardboard for the function $z' = f(y')$ and the function $z' = y'$ are kept stable (hence the light source is steadily perpendicular to the water line represented by screen cardboard and to the y' -axis) and set of first function cardboards is arbitrarily moved or turned by the water-line simulator, then the photocell current of one Gray's unit

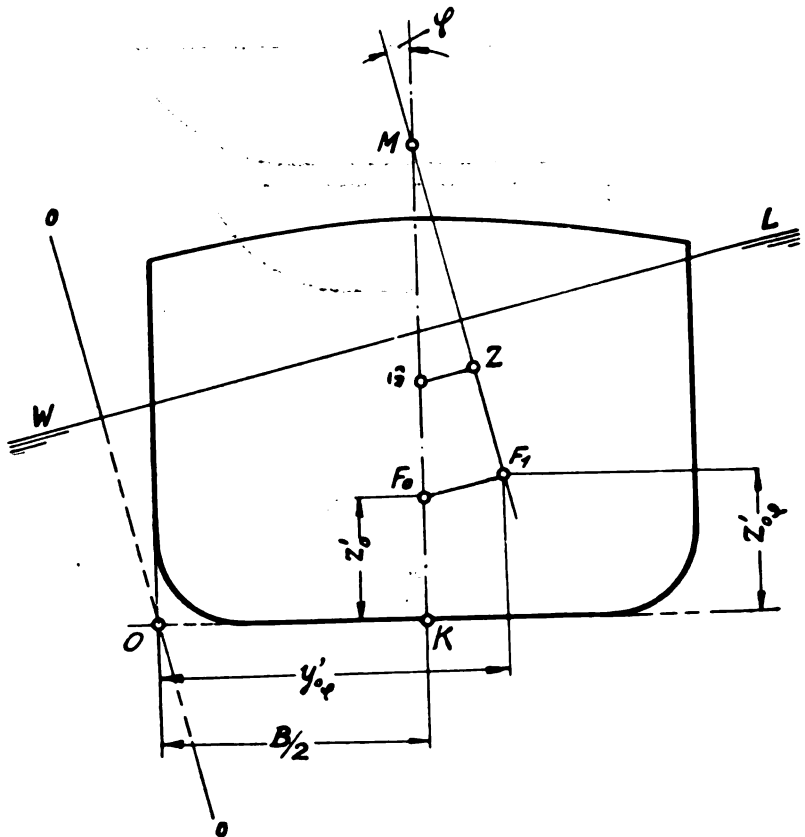


Fig. 34

will continuously be the measure of $M_t(y') = \int f(y') \cdot y' \cdot dy'$, i. e., of the value of the moment of area of the corresponding cross section about an axis $0-0$ perpendicular to the momentary water plane WL . Hence the output voltage for all the dark cameras of the instrument (I-series circuit included by the switch $3I$) will show the moment of displacement $M(y') = \int M_t(y') \cdot dx$ competent for the evaluation of the righting arm GZ .

The apertures of the second set of function cardboards 79 , while representing the simple function $z' = y'$, should correspond to the mere

isosceles and right-angled triangles. But, in order to comply with the condition of coplanarity, these triangles must be somewhat extended; thus they will be mere right-angled triangles, and not isosceles at the same time. They will be equal for all the cross sections and can be made once and for all.

Hence here we treat the heeling of the ship. But, in contradistinction to the work with the „needle“ instruments where this was performed exclusively by buttock-and-bow sections, we do it by cross sections here. *This renders it possible to treat both heeling and trimming at the same time.* (Cross sections are mandatory for heeling problems: either they or the screen cardboards have to be turned and the heeling is already simulated; and as there is no obstacle for the function cardboards or the screen cardboards to reach different drafts within their cameras by the mere inclination of the water line simulator, trimming can necessarily be simulated at the same time).

Besides, it should be mentioned that the last outlined procedure (GZ-method) reminds us of the well known Fellow-Schulz method (Ref. [7]) of evaluating „righting-arm“ curves.

If in the case of two sets of cardboards (function cardboards $z' = f(y')$ and $z' = y'$) the set of line-slot screen cardboards is placed against the set of function cardboards, then the result will be the value $M_k(y')$. And if in this case there is a quadratic-law aperture instead of the linear-law one (triangle aperture), then the result will be $J_k(y')$ instead of $M_k(y')$.

Thus the elaboration of both fundamental problem No. 1 and fundamental problem No. 2 by the optical instrument has been set forth.

If $M(z')$ is evaluated by the cardboards representing vertical moments of buttock-and-bow sections, then 3 sets of function cardboards are necessary (cross sections, buttock-and-bow sections and vertical moments of buttock-and-bow sections) for both fundamental problems.

If $M(z')$ is evaluated by the two sets of coplanar longitudinal sections, then beside the set of cross-section cardboards two sets of buttock-and-bow-section cardboards are also necessary, hence 3 sets are required in all for both fundamental problems.

If $M(z')$ is avoided by applying the direct evaluation of GZ, then only one set of function cardboards is required, i. e., cross sections (the sets of right-angled and quadratic-law-aperture cardboards are made once and for all). This is due to the fact that in this case both heeling and trimming can be treated on the basis of cross sections only.¹⁰

¹⁰ It is possible to treat both fundamental problems on the basis of only one set of function cardboards whereby no avoiding of the evaluation of the $M(z')$ -value is made so that the mentioned checking by y_0 and z_0 (Ref. [17]) is retained. This possibility will be shown at a later stage in connection with the so-called concentrated-integration optical instrument.

The variant of the optical instrument which has just been displayed will be spoken of as an individual-integration optical variant (I. I. optical variant; each of the dark cameras relates to one ship's section so that the integration is performed individually for each section).

The possibility of the simultaneous treatment of both trimming and heeling (which is feasible with this variant generally and not only with the direct GZ method) is especially important, the need for such a treatment being increasingly pointed out (Ref. [9]).

It may be remarked that there is no calculating preparation with the I. I. optical variant. And technical preparation consists only in cutting the apertures in the sets of cardboards (to be made by a cutting pantograph).

Instead of cardboards other materials (tin plates and the like) can be used, too.

Another solution is to draw the functions (ship's sections) on a sheet of tracing paper or any transparent paper which will be inserted in some frame. The surface of the paper beyond the actual ship's section should be blackened by Indian ink. This is possibly a better method, for no cutting is required so that better (more precise) functions can be set to the uninstrument. The grade of the transparency of the paper is to be taken into account as the scale factor. It can be ascertained very easily (prior to the work of the instrument) by the mere comparison of the photocell current caused by the light flux passed through the paper as against that caused by the free flux.

A further possibility is to use the ordinary film tape for function „cardboarding“ purposes (snapshots are taken of larger drawings) whereby a considerable reduction of the overall dimensions of the instrument can be achieved.

b) CONCENTRATED INTEGRATION

1) GENERAL CONSIDERATIONS AND C. I. MECHANICAL INSTRUMENTS

With the individual-integration variants of the two-integration instruments each of the function generators has to be provided with a pair of integrators interconnected as shown in Fig. 29. This obviously results in both a very costly and a rather inadequate instrument. To avoid these inconveniences a specific group of two-integration instruments, called „concentrated-integration instruments“ (C. I. instruments), may be derived from the I. I. group of instruments. The establishment of the relations valid for the C. I. ship analyzers will be discussed with the mechanical variant of the analyzer's pick-up assembly, *but these relations will be valid generally.*

Referring back to Fig. 7, we see that there is no difficulty to introduce another adder h''' which would add the movements of the abscissa-commanding elements r .¹¹ An outline of the new variant is represented by Figs. 35 and 36. Thus there are 3 old multiplier-adders h , h' and h'' in this instrument¹² now (I-, ILA- and IQA-series of coefficients respectively) and a simple adder h''' whose output gives the sum of the effectuated movements of the plates 37, or, speaking generally, of the abscissa-forming elements r of function generators.

If an integrator k is attached to the output of the simple adder h''' on one side and to the output of the multiplier-adder h on the other side (Fig. 36), the output of this integrator — under certain conditions — will be continuously giving the measure of the displacement D if the ship's sections are represented by the function generators. If another integrator k' is attached to the instrument to which the output of the multiplier-adder h' and that of the simple adder h''' are fed, then — if some conditions are fulfilled — the values of the moments $M(x)$ or $M(y')$ will be given by the output of this integrator according as there are the A_i or A_j functions which are represented by function generators.

Hence almost the whole of the fundamental problem No. 1 would be resolved in this way (there remains only $M(z')$ to be solved; the integrator l will be engaged for this purpose which will be explained at a later stage).

¹¹ Carriages 3 being fixed, abscissa-commanding elements are the plates 37 bearing tapes 1. These plates are displaced by the water-line simulator g .

¹² Leverage transmission is applied in Figs. 35 and 36 instead of gear transmission 12 (Fig. 7).

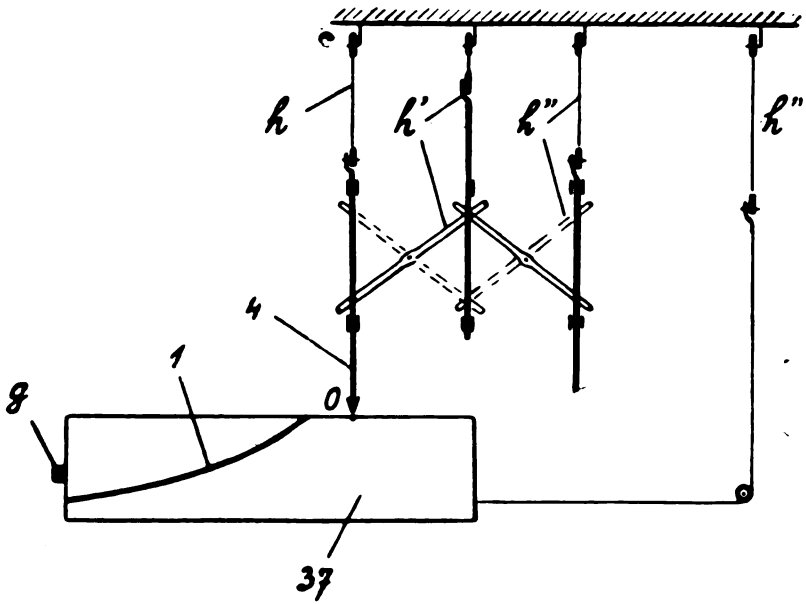


Fig. 35

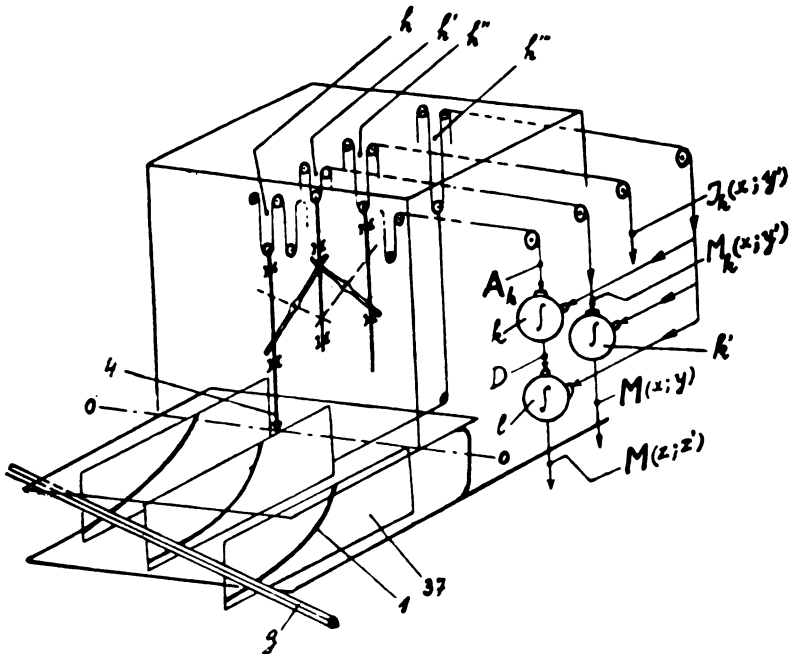


Fig. 36

As to the fundamental problem No. 2, it is resolved in the same way as earlier, hence the results have simply to be read at the outputs of the three old multiplier-adders directly (i. e., before the integrators whereby it is irrelevant whether these integrators are included or excluded).

Hence, this variant seems to be very efficient. Instead of as many pairs of integrating units as there are function generators, only 2 or 3 integration units are required. The integration is carried out in concentrated places for all the stations, i. e., for all the function generators (concentrated integration, hence „concentrated-integration“ variant, C. I. variant).

However, a considerable restriction is implied with this variant of the instrument. In order to account for it, we must refer to the mathematical background of the instrumentation.

With the I. I. variant whereby every function generator possessed a pair of integrators (Figs. 27 and 55) the operation which was performed in the runs Nos. 1 and 2 [$s = 0$ in (4), hence only the result of the first integrator k (disk 48, friction wheel 49), i. e., the movement of the rack 53 is valid] was as follows:

$$\begin{aligned} \boxed{\int} i^r \left(\int_x y_t(z) d z_t \right) \Delta_t = c_1 \int_{z_1} y_1(z) d z_1 \Delta_1 + \\ + c_2 \int_{z_2} y_2(z) d z_2 \Delta_2 + \dots + c_n \int_{z_n} y_n(z) d z_n \Delta_n \end{aligned} \quad (13)$$

By c_t the coefficients from the series I and ILA (or, in other runs, IQA) are designated. They, together with Δ_t , relate to the „second“ (approximate) integration $\int i^r () \Delta_t$ in (4).

Relation (13) clearly indicates that the integration is effectuated *on the spot* (just after the function generators) and the summation is performed afterwards.

What we do with the new variant (C. I. variant) is as follows:

$$\begin{aligned} \int_x \left(\sum c_t y_t(z) \Delta_t \right) \cdot \sum d z_t = \\ = \int_x (c_1 y_1(z) \Delta_1 + c_2 y_2(z) \Delta_2 + \dots + c_n y_n(z) \Delta_n) (d z_1 + d z_2 \dots + d z_n) \end{aligned} \quad (14)$$

Relation (14) clearly indicates that first two independent summations are performed and then only one integration is effectuated.

The relation (14) can be transformed into the relation (13) only if all the factors dz_i are equal in (14) and (13). [Otherwise the terms $c_i \int y_i(x) \Delta_i dz_i$ would appear in (14) and render it impossible for (14) to be transformed into (13)]. Then applies:

$$\begin{aligned}
 \int_x (c_1 y_1(x) \Delta_1 + c_2 y_2(x) \Delta_2 + \dots + c_n y_n(x) \Delta_n) \cdot (dz_1 + dz_2 + \dots + dz_n) &= \\
 = \int_x (c_1 y_1(x) \Delta_1 + c_2 y_2(x) \Delta_2 + \dots + c_n y_n(x) \Delta_n) \cdot n dz &= \\
 = n (c_1 \int_x y_1(x) \Delta_1 dz + c_2 \int_x y_2(x) \Delta_2 dz + \dots + & \\
 + c_n \int_x y_n(x) \Delta_n dz) = n \boxed{=} i^r \left(\int_x y_i(x) \cdot dz \right) \Delta_i &
 \end{aligned}
 \tag{15}$$

The factor n affects the scale in which the end results are delivered. Notwithstanding this, we see that (14) has in fact been transformed into (13) under the mentioned conditions.

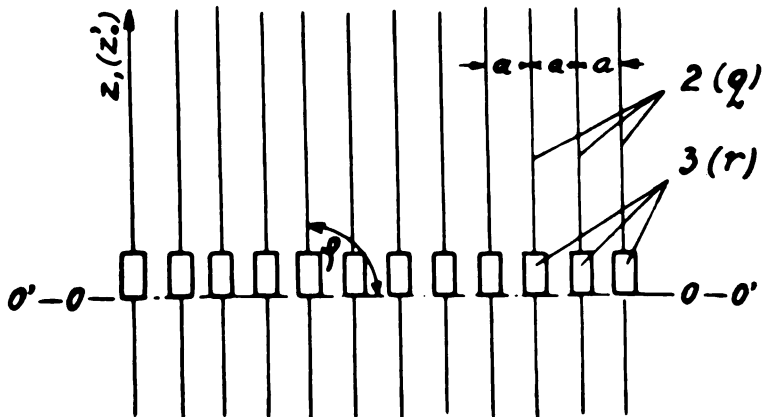


Fig. 37

The physical meaning of the condition mentioned (values dz_i to be equal for all stations) with the C. I. variant is that in the moving along the paths of the abscissa-commanding elements r the water-line simulator g can only be translated and not rotated at the same time. Translation keeps all dz_i equal, while the essence of the rotation is just the fact that the values dz_i are unequal.

Hence, while the I. I. variant is based on the relation (13) where dz_i are not necessarily equal ($dz_1 \neq dz_2 \neq \dots \neq dz_n$) so that both translation and rotation of the water-line simulator (i. e., quite an arbitrary movement) is permissible with it, the C. I. variant can tolerate only translation of the

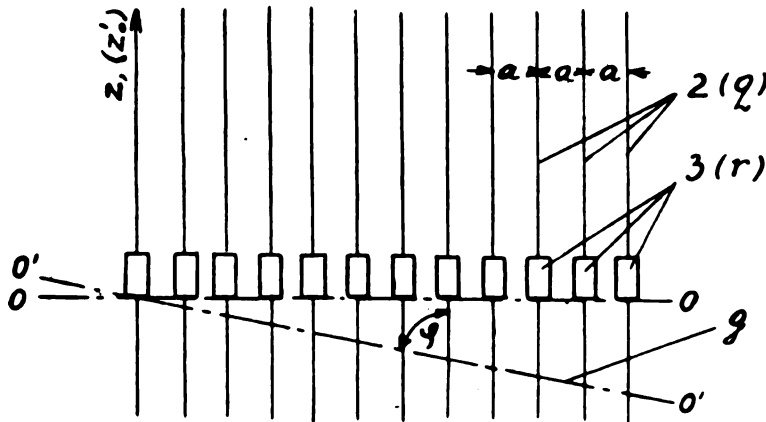


Fig. 38

water-line simulator. Thus with the latter variant the angle φ of the water-line simulator against the paths q (Fig. 38) must be constant within a run; changes of the angle have to be made only between the successive runs.

Thus we may formulate the first rule of the concentrated-integration instruments in this way:

Rule No. 1 of the concentrated-integration instruments:

The angle φ between the water-line simulator g and the paths q of the abscissa-commanding elements r must be constant during a run. In other words, the water-line simulator can be only translated (and not rotated) in its displacement against the abscissa-commanding elements r .

However, there is another prescription which is applicable to these instruments, and also to the I. I. ones, since it results from the concept of the two-integration instruments rather than from that of the concentrated-integration ones (both the I. I. instruments and the C. I. ones are two-integration instruments):

With the two-integration instruments the starting position of the water-line simulator must be either before the base line $0-0$ of the instru-

ment, or on the base line $0-0$ itself.¹³ This is implied by fact that both integrations are performed by the instrument; hence the needles (function generators in general) do not only read off the values of the curves, but also take part in the integration of the curves which are „read off“ by them.

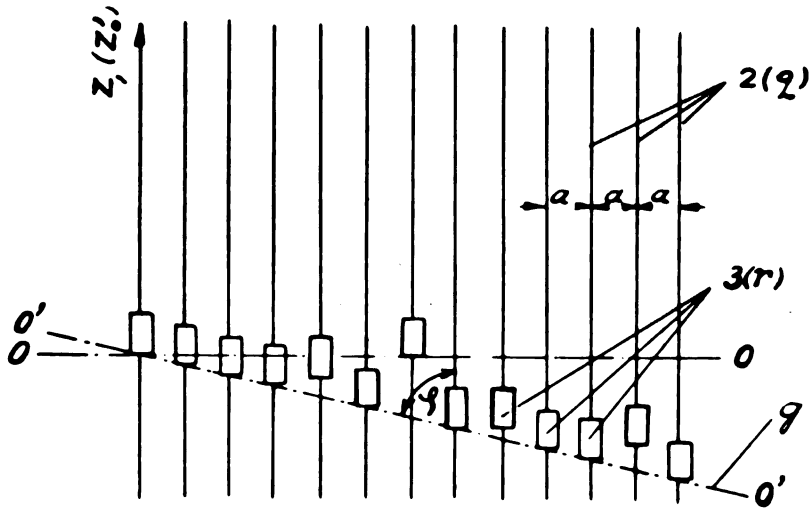


Fig. 39

And as the integration of the curves must begin from their origin [see lower limits of the integrals \int in the formulae (4) and (5)], the water-line simulator must start moving from the base line $0-0$ at least or even from before it.¹⁴ This will be called the **first rule of the two-integration instruments**.

If the ship is in upright position, hence $\varphi = \text{const.} = 90^\circ$, then the water-line simulator's position $0'-0'$ can coincide with the base line $0-0$ (Fig. 37). In this special case it would be sufficient for the adder h''' to deliver to the integrator the datum of the displacement of the element r of only one function generator.

¹³ The base line $0-0$ of the instrument is a straight line which corresponds to the keel, i. e., to the bottom of the ship and from which begin the values $y(z)$ (for the longitudinal plan) and $x(z)$ (for the transversal plan). Line $0'-0'$ corresponds to the starting position of the water-line simulator and it has the form of the water-line simulator itself.

¹⁴ This is not the case with the one-integration instruments. With these instruments the functions represented by function generators are not integrated by the instrument. Only the „ordinates“ of these functions are read off so that the calculation may begin from any position of the water-line simulator (no matter whether before or behind the line $0-0$).

If the ship is in an inclined position, hence $\varphi = \text{const.} \neq 90^\circ$, the starting position of the water-line simulator g (line $0' - 0'$, Fig. 38) does not coincide with the base line $0 - 0$. In this case the elements r are engaged successively one after another, the adder h''' is fully active, but the scale factor therefore varies in intervals [n varies in (15)].

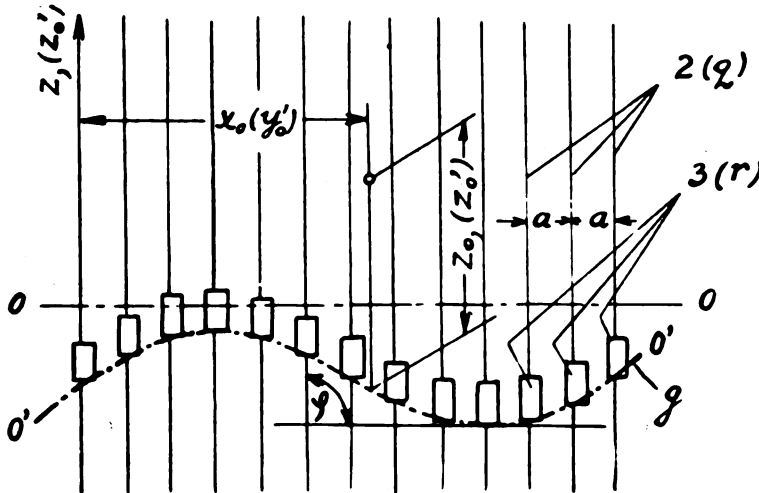


Fig. 40

Before the starting of a run all abscissa-commanding elements r are set (Figs. 38 and 39) either on the base line $0 - 0$ or before it. The very distance between the starting position of the water line simulator $0' - 0'$ and the base line $0 - 0$ is insignificant („idle“ distance), since the ordinates of the functions are zero there [$y_t(x) = 0$ for the longitudinal plan and $x_t(x) = 0$ for the transversal plan]. This being so, we can set forth the following rule:

*With the two-integration instruments the abscissa-commanding elements r of function generators may be positioned, before a run, at any place between the lines $0 - 0$ and $0' - 0'$, Figs. 38 39, 40. (Line $0 - 0$ is the base line of the pick-up assembly, and line $0' - 0'$ is the starting position of the water-line simulator). This will be called the **second rule of the two-integration instruments**.*

Turning back to the concentrated-integration instrument only, the following can be said: The concept of the concentrated integration implies no restrictions to the speed of displacement of the water-line simulator.

This speed need not be uniform.¹⁵ It is not even necessary that the water-line simulator be moved in one direction invariably; periodical backward movements do not deteriorate the calculation in the least.

In order to evaluate the value of $M(z)$ or $M(z')$ [run No. 3, $s = 1$ in (4), both integrators active in Fig. 27, see also Table III] by the C. I. variant of the instrument, one integrator more should be attached to the former ones, and that is just the above-mentioned integrator l (Fig. 36). Hence the output of the simple adder h''' of the instrument is fed not only to the integrators k and k' , but also to the integrator l . Beside this datum the latter integrator is fed also by the result of the first integrator k (see also Fig. 29). It should be remarked that the output of the adder h''' is fed to the ordinate input of the integrator l , whilst the output of the integrator k is fed to the abscissa input of this integrator.

Hence the integrators k and l are basically connected as illustrated in the scheme in Fig. 29 with the only difference that it is not the movements from individual stations which are delivered to them, but the sum of the movements of all the stations.

The output of the second integrator l will represent thereby the value of $M(z)$ or $M(z')$ according whether there are the cross sections or the vertical fore-and-aft sections which are represented by function generators.

However, the inclusion of the integrator l which is connected in series with the integrator k entails some new restrictions to the C. I. variant of the instrument.

Turning again to the mathematical background, we see that the following is performed by this variant now (in line of the integrators k and l only):

$$\int \{ d [\underbrace{\int (c_1 y_1(z_1) \Delta x_1 + c_2 y_2(z_2) \Delta x_2 + \dots + c_n y_n(z_n) \Delta x_n) \cdot (dz_1 + dz_2 + \dots + dz_n)}_{\text{Relation (14); integration in the first integrator } k}] (z_1 + z_2 + \dots + z_n) \}_{z_1, z_2, \dots, z_n} \quad (16)$$

Integration in the second integrator l

However, the true relation which should be underlying the evaluation of $M(z)$ is

$$\boxed{\int_{z'} i^r \left(\int_{z'} y_1(z) \cdot z \cdot dz \right) \Delta_1 = c_1 \int_{z'} y_1(z) z_1 dz_1 \Delta_1 + c_2 \int_{z'} y_2(z) z_2 dz_2 \Delta_2 + \dots + c_n \int_{z'} y_n(z) z_n dz_n \Delta_n} \quad (17)$$

¹⁵ This is valid only inasmuch as mechanical integrators (or, speaking more precisely, no time-based integrators) are in question. When using the integrators based on time, then speed must be uniform, but this prescription is due to the type of integrators used rather than to the concept of the concentrated integration.

Hence, to transform (16) into (17) not only the previous conditions (dz_i to be equal) must be fulfilled, but also the new ones are imposed. Namely all the z_i -values must also be equal now [otherwise the terms $c_i \int y_i(z) \Delta_i dz_i z_i$ would appear in (16) and render it impossible for (16) to be transformed into (17)].

With the old conditions (dz_i equal) the relation (16) is first transformed into the form

$$\begin{aligned} & [n c_1 \int_x y_1(z) \Delta_1 dz + n c_2 \int_x y_2(z) \Delta_2 dz + \dots + \\ & + n c_n \int_x y_n(z) \Delta_n dz] \cdot (z_1 + z_2 + \dots + z_n) \end{aligned} \quad (18)$$

for which, after the introduction of the new conditions (z_i equal), holds

$$\begin{aligned} & [n c_1 \int_x y_1(z) \Delta_1 dz + n c_2 \int_x y_2(z) \Delta_2 dz + \dots + n c_n \int_x y_n(z) \Delta_n dz] \cdot n z = \\ & = n^2 c_1 \int_x y_1(z) \Delta_1 z dz + n^2 c_2 \int_x y_2(z) \Delta_2 z dz + \dots + n^2 c_n \int_x y_n(z) \Delta_n z dz = \\ & = n^2 \boxed{\int_x y_i(z) z dz} \Delta_i \end{aligned} \quad (19)$$

Hence after allowing for n^2 , which affects only the scale to which the results are represented, we realize that (16) has to be transformed into (17) under the above-mentioned conditions.

While the old conditions (dz_i equal) meant that the angle of the water-line simulator towards the paths of the abscissa-commanding elements r had to be constant during a run (but there were no restrictions with regard to the angle itself), the new conditions (z_i equal) mean that this angle has to be 90 degrees. For, all the values z_i will be equal (see Fig. 37) only if the water-line simulator is perpendicular to the paths q of the abscissa-commanding elements r (ship upright).

Besides, it did not matter hitherto whether the water-line simulator was a straight line or a wave-form line. Both cases were possible. But in the last variation of the C. I. variant the wave-form line is unacceptable. The base of the water-line simulator can be perpendicular to the paths of the elements r , but the wave form of its active part renders it impossible for z_i to be equal.

Thus the C. I. variant, which appeared very attractive from the manufacturing point of view, turns out to be of a very reduced field of application: Only the even-keel positions of the ship and the straight water line cases seem to be capable of being treated by it.

Nevertheless, a revision of our derivations can afford a full rehabilitation to the C. I. variant.

In all the derivations presented so far it has been tacitly assumed that the values z_i started from the base line $0-0$ of the instrument. Indeed, this is quite a natural assumption, the base line $0-0$ representing the keel or, generally, the bottom of the ship from which on (along the draft, i. e., along the paths q of the elements r) the functions representing the ship's sections are set. But as to the relations (13) through (19) themselves, they are not bound by any prescription concerning the starting points of the z_i -s. As to these relations, the abscissa-commanding elements r of function generators can be readily set on the starting position $0'-0'$ of the water-line simulator before the starting of a run (see Fig. 40) instead of on the base line $0-0$ as it was tacitly supposed to be the case earlier (Fig. 38)

If the elements r are put on the starting position $0'-0'$, then, as the ship-section functions are set invariably only from the base line $0-0$ on, the „idle“ distance between the lines $0'-0'$ and $0-0$ (which by the setting of the elements r on the line $0'-0'$ came also to be included in the calculating range) will be characterized by the existence of the z_i -values both theoretically and practically, while the $y_i(x)$ - or $x_j(z)$ -values will exist only theoretically. The latter values will be equal to zero in the „idle“ distance, and will come into practical existence only from the line $0-0$ on.

Practically, the whole matter can be reduced to the fact that the same ship as earlier is calculated now (Fig. 40), — with the only difference that the reference line for the moments $M(x)$ [or $M(x')$] is not the stable line $0-0$, but the line $0'-0'$ which is variable from run to run.

Hence, instead of the constant rectangular co-ordinate systems $0, x, y, z$ and $0', x', y', z'$, (see Fig. 1), now (Fig. 41) we have the oblique systems $0, x, y, z$ (longitudinal plan) and $0', x', y', z'$ (transversal plan) whereby the axes x and y' (which are either straight or in the form of a wave) sink with every new run by the step angle α . The obliquity of the new co-ordinate systems is by far a minor disadvantage of the new schemes than the major advantages which have been brought forth by them.

First of all, all the z_i -values have become equal now, regardless of the obliquity of the water-line simulator against the paths of the elements r (and regardless of its possible wave form as well). Hence the C. I. variant

is applicable generally, i. e., for both upright and inclined (or trimmed) positions of ships. The wave-form line is applicable, too. Simply the elements r have to be set on the starting position $0' - 0'$ (see Fig. 40) of the wave-form

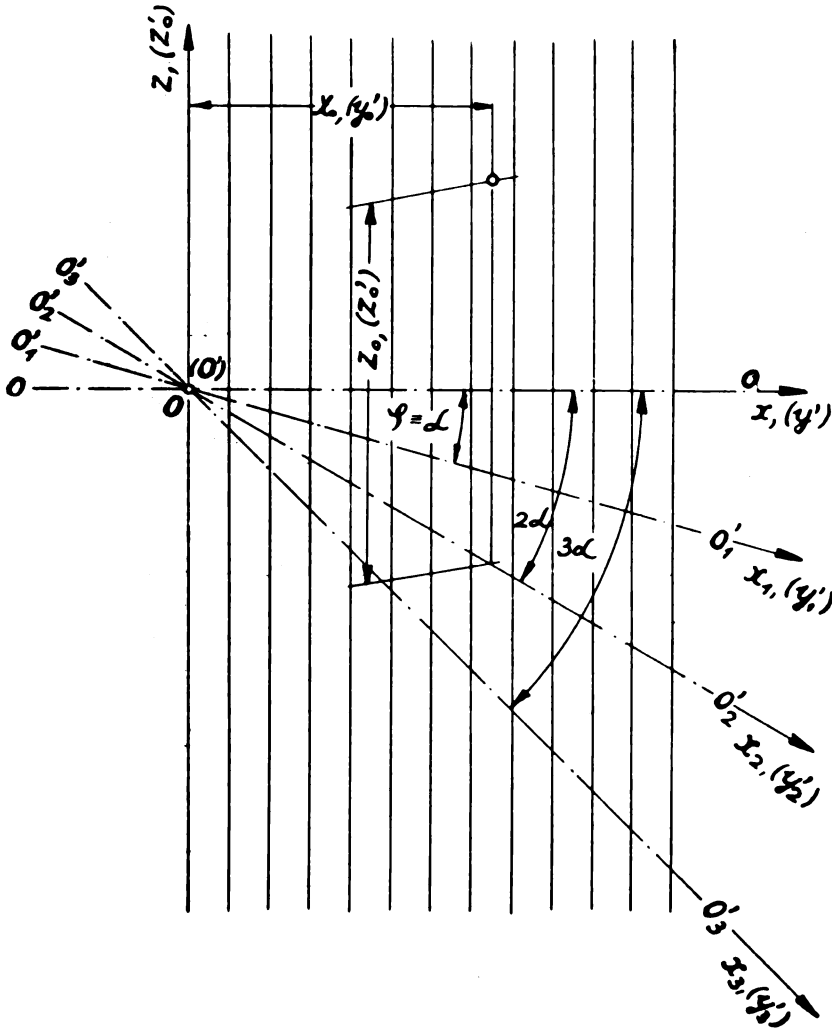


Fig. 41

water-line simulator which is chosen so that all the moving parts r of function generators b have to be before the base line $0 - 0$ prior to a run. As all the moments are referred to the starting position, hence to the wave-form line

$0' - 0'$, the leverages z_0 (or z_0'), calculated by $z_0 = \frac{M_z}{D}$ (or $\frac{M_z'}{D}$), have to be laid off also from $0' - 0'$ (Fig. 40).

Then, the number of the actuated elements r is constant during a run now, viz. all the existing elements r are simultaneously engaged. This leads to a favorable situation whereby the factor n in the relations (15) and (19) is constant, hence that the scale is invariable during a run now. (With the earlier solutions — Fig. 38 — the individual elements r were engaged successively one after the other, hence the scale changed by intervals).

Finally, the equality of z_i -values makes it that there is no material need for the adder h''' to be introduced into the instrument. All the z_i -values being equal, only one of them (displacement of one of the elements r) may be transmitted to the integrators k, k' and l (sum of them may be allowed for by the scale factor). Instead by the output of the adder h''' , the integrators can be fed by the displacement z of the water-line simulator g which would be transmitted to them from the water-line simulator directly (Fig. 56).

However, once the datum in question being fed from the water-line simulator and not from any of the elements r , the abscissa-commanding elements r need not be put on the starting position $0' - 0'$ before a run. Owing to the fact that $y_i(z)$ - [or $x_i(z)$]-values are equal to zero in the idle distance (between the lines $0 - 0$ and $0' - 0'$) and also that the value z is delivered directly from the water-line simulator, the elements r may be put, before a run, at any place in the „idle“ distance between the lines $0 - 0$ and $0' - 0'$.¹⁶ Since the common z -value is delivered by the water-line simulator g , all z_i -values (for all stations) are automatically both equal and begin from the starting line $0' - 0'$ on. Therefore the leverage z_0 (which is calculated by the formula $z_0 = \frac{M(z)}{D}$ after the values $M(z)$ and D have been obtained by the instrument) refers also to the starting line $0' - 0'$.

Thus we can formulate the second rule of the concentrated integration instruments in this way:

Rule No. 2 of the concentrated-integration instruments:

When settling the results of computation, the leverages z_0 , ($z_0 = \frac{M(z)}{D}$), must always be laid off from the starting position $0' - 0'$ of the water-line simulator (Fig. 40) whereby the common abscissa z_i of function generators starts and proceeds as the displacement of the water-line simulator.

¹⁶ Thus the second rule of two-integration instruments is valid for the run No. 3 of the instrument, too. (It seemed to be excluded when we said that the elements r have to be put on the starting position $0' - 0'$ of the water-line simulator).

Remark should be made that, whilst the first rule of the concentrated integration instruments is valid generally, the second one refers only to the run No. 3 (3') of the instrument (evaluation of $\mathbf{M}(z)$, $\mathbf{M}(z')$, see Table III).

Thus we see that the C. I. variant of our instruments comes to be fully rehabilitated. In fact, this variant turns out to be one of the most efficient solutions of our instruments. There are only 2 to 3 integrators (see Fig. 36; the three integrators need not be included all simultaneously; thus the integrator k' can be eliminated and either of the integrators k or l can be substituted for it).

In one run of the water-line simulator any of the values \mathbf{A}_k , $\mathbf{M}_k(x)$, $\mathbf{J}_k(x)$, D , $\mathbf{M}(x)$, $\mathbf{M}(z)$ will be obtained in case the function generators are adjusted to represent the cross sections (work on longitudinal plan), and any of the values \mathbf{A}_k , $\mathbf{M}_k(y')$, $\mathbf{J}_k(y')$, D , $\mathbf{M}(y')$, $\mathbf{M}(z')$ (see Fig. 36) will be obtained if the function generators are adjusted to vertical fore-and-aft sections (work on transversal plan — „reduced ship“).

C. I. variant being a two-integration variant, only two settings of the function generators (setups Nos. 4 and 5 of the Table I) are required with this instrument.

The indirect problems cannot be solved by C. I. variant straightforwardly, the angle of inclination of the water-line simulator having to be constant during a run. But as neither the speed¹⁷ nor the direction of the water-line simulator's movement are bound to be invariable, the instrument is all but capable of treating the indirect problems. For the rest, the indirect problems are solved by means of a series of direct ones, so that in the end there is no direct-problem-solving instrument which cannot be accepted also as an indirect-problem-solving one.

Indeed, the oblique co-ordinate systems are implied by the C. I. variant instead of the rectangular systems, but this is a point which concerns only the settling of the results after the application of the instrument rather than the running of the instrument itself. And as the allowance for the obliquity is to be made only for every new angle of the water-line simulator rather than for every significant spot in the diagram (one angle relating to a lot of spots), this difficulty in settling the results is by far minor than it seems at first. For the rest, it is encountered only in the run No. 3 (3'), other runs being free from it.

In Figs. 35 and 36 the principal schemes only of the C. I. mechanical variants of the instrumentation have been presented.

¹⁷ The speed of the water-line simulator is arbitrary only in the case such integrators are applied whose operation is not based on time.

However, it is hardly necessary to say that not only mechanical elements (function generators, multiplier-adders, integrators) can be used for the construction of a C. I. variant along the previous lines. Electrical, optical and other elements can also be used. If the function generators or only their abscissa-commanding elements r are set in accordance with the model disposition, and if prescriptions set by the two rules of the C. I. instruments are fulfilled so that only a small number of integrators is necessary, such instruments will necessarily be C. I. variants and accordingly will also be spoken of as such. Block diagrams for the bulk of the C. I. variants are shown in Figs. 56 and 57.

But, before concluding the present discussion of the C. I. instruments, let us present a somewhat different approach to their theoretical foundations.

The derivation of the rules valid for the C. I. instruments has been based on Eqs. (15), (18) and (19), whereby Eq. (15) shows the way in which Eq. (14) is transformed into Eq. (13) due to dz_i -values being equal for all stations, whilst Eqs. (18) and (19) show the way in which Eq. (16) is transformed into Eq. (17) due to both dz_i - and z_i -values being equal for all stations.

However, the basic rules of the C. I. instruments can be arrived at also in another way, which, in addition, is very simple.

First, let us remark that the standard designation for the contour line of the i -th cross section („ i “ is index for the x -axis, „ j “ for y -axis, etc.) is $A_i = y_i(z)$. In fact, having in view the ship as a whole rather than an individual cross section, this designation should read $A = y(x, z)$. Thus we see that index „ i “ with y_i in the standard designation refers to the argument x in the complete designation. For the sake of simplicity this argument has been omitted in the standard designation. The case is analogous with $\Delta_i, A_j = x_j(z), \Delta_j$, etc., for which the complete designations should respectively read $\Delta x, A = x(y, z), \Delta y$, etc.

Second, let us remark that out of 4 basic terms (results) of our instruments, viz. (4), (5), (7) and (8), only the first two relate to the fundamental problem No. 1 and thus to the range of the two-integration instruments. Thus, treating only the first one [since (5) is quite analogous to (4)], the two-integration instruments as a whole are necessarily treated thereby.

Turning now to the term (4) which, written in complete designations, reads

$$\int_{x=0}^{x=m} (x^r \int y(x, z) \cdot z^s \cdot dz) \Delta x \quad (20)$$

we see that, mathematically speaking, it is but a double integral. And it is well known that in the case of the double integral the inner, or first, integral can exchange its place with the outer, or second, integral whereby the result of the double integral remains unaltered. Applying this rule to (20) we obtain

$$\int_{x=0}^{x=m} \left(x^r \int_z y(x, z) \cdot z^s \cdot dz \right) \Delta x = \int_z \left\{ \int_{x=0}^{x=m} x^r \cdot y(x, z) \right\} \Delta x \cdot z^s \cdot dz \quad (21)$$

In fact, if z -values were different for individual x -stations, [$z=f(x)$] then the transformation would read like this:

$$\int_{x=0}^{x=m} \left(x^r \int_z y(x, z) \cdot z^s \cdot dz \right) \Delta x = \int_z \left\{ \int_{x=0}^{x=m} [x^r \cdot y(x, z) \cdot z^s] \Delta x \right\} dz \quad (22)$$

If not only z -values were different for individual x -stations, but also dz -values were so, then dz should be also placed in the brackets (before Δx) on the right-hand side of Eq. (22). The exchange of integrals' places would be quite trivial then.

Thus we see that the values dz and z must be independent from x , i. e., that they must be equal for all the stations in order that the transformation (21) be valid.

The mentioned conditions of equality are just the points underlying the two rules of the C. I. instruments which have been derived at an earlier stage.

The left-hand side of Eq. (21) represents what is ordinarily done by the naval architect when calculating a ship on the longitudinal plan: integration of each cross section individually with a subsequent integration throughout the length of ship. The right-hand side of Eq. (21) represents the addition (in fact integration, since Simpson's multipliers are applied, of the half-breadths of ship followed by an integration versus the height of ship. Hence the water planes are in fact calculated here and then integrated throughout the height of ship, but, contrary to common practice, the ordinates of the water-plane curves are taken thereby from the cross-section curves rather than from the water-plane ones.

The right-hand side of Eq. (21) represents the very operation which is performed by the C. I. instruments.

Thus we see that the transformation (21) leads to the operation performed by the C. I. instruments and that it is possible only if the conditions underlying the two rules of the C. I. instruments are fulfilled.

2) C. I. ELECTRICAL INSTRUMENTS

In order to present a possibility of making two-integration computers based mainly on electrical function generators and integrators, it is necessary first to consider a fundamental scheme of the modern analog computing technique.

The scheme in Fig. 42 is being considered. The tensions $e_{i_1}, e_{i_2}, \dots, e_{i_n}$ (index „i“ = input) are made to pass through the impedances Z_1, Z_2, \dots, Z_n (resistors with resistances resp. $\rho_{i_1}, \rho_{i_2}, \dots, \rho_{i_n}$) and then are fed to the high-gain electronic amplifier 75. The amplifier is provided by a negative feedback loop including the impedance Z_f . By virtue of the gain A of the amplifier being very high ($A = 10^8 - 10^9$), the amplifier's input terminal (junction point M , Fig. 42) is maintained practically at ground potential (References [8], [9], [13], [18]). If the feedback impedance Z_f is a resistance ($Z_f = R_f$), the scheme in Fig. 42 offers a multiplier-adder. In this case the nodal equation for point M determines the output tension of the amplifier e_0 (index „o“ = output) for which applies:

$$e_0 = - \left(\frac{Z_f}{Z_{i_1}} e_{i_1} + \frac{Z_f}{Z_{i_2}} e_{i_2} + \dots + \frac{Z_f}{Z_{i_n}} e_{i_n} \right) = - \sum_{j=1}^n k_j e_{i_j} \quad (23)$$

where

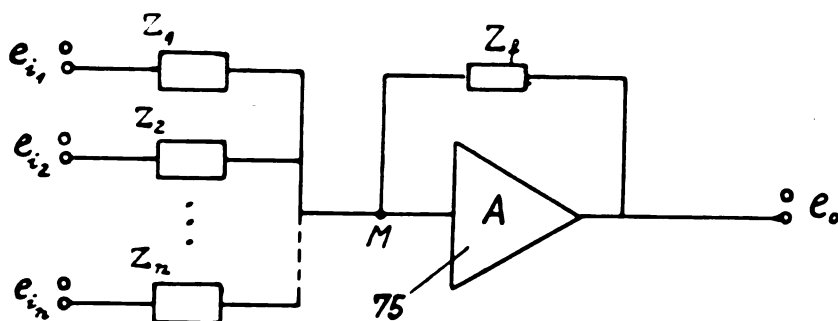
$$k_j = Z_f / Z_{i_j} = R_f / \rho_{i_j} \quad (24)$$

Hence this scheme represents necessarily a multiplier-adder unit. It can directly be applied to any of the addition schemes presented earlier regardless of the kind of the function generators used for the production of the input tensions $e_{i_1}, e_{i_2}, \dots, e_{i_n}$. An example is given in Fig. 20 where the scheme from Fig. 19 is applied. The same outline is presented in Fig. 43, too. According to these schemes the input impedances $Z_{i_1}, Z_{i_2}, \dots, Z_{i_n}$ from the scheme in Fig. 42 are qualified as resistors 30 (Figs. 19 and 20). As a matter of fact, they are made as 3-tap resistors and the switch 31 is also included just as in Fig. 20. Taps are made so that by the switch 31 the ratios $k_j = Z_f / Z_{i_j}$ ($j = 1, 2, \dots, n$) may be established corresponding to the known series of coefficients I, ILA and IQA.

The generators of input tensions $e_{i_1}, e_{i_2}, \dots, e_{i_n}$ correspond to the potentiometers 28 in Figs. 19 and 20. Regardless of the method of generating these tensions, the disposition of the generators, i. e., of their abscissa-commanding elements r (in Fig. 43) complies with the geometrical and other rules of the model of the ship (symbolically represented in Fig. 43 by dotted

rectangular) in her environment (water-line generator g), to which the tapping of the impedances $Z_{1,}$, $Z_{1,}$, $Z_{1,}$ has to be conformed strictly, too.

Referring back to the independant scheme in Fig. 42 we see that a multiplying, adding and integrating unit at the same time is represented by



$$Z_{1,2,\dots,n} = \rho_{1,2,\dots,n} = \text{INPUT RESISTANCES}$$

$$Z_f = R_f \cdot (\text{SUMMATION}), \quad Z_f = \frac{1}{C_f p} \quad (\text{INTEGRATION})$$

Fig. 42

it if the feedback impedance Z_f is realized by a capacitance instead of by a resistances (References [8], [9], [13], [18]). In this case — considering the process of charging the capacitor and applying nodal equation for the point M again — the following term is obtained for the output tension of the amplifier:

$$e_o = -\frac{1}{C_f} \int_0^t \left(\frac{e_{i_1}}{\rho_{i_1}} + \frac{e_{i_2}}{\rho_{i_2}} + \dots + \frac{e_{i_n}}{\rho_{i_n}} \right) dt \quad (25)$$

where

ρ_{ij} = resistances of the input resistors, ($Z_{ij} = \rho_{ij}$),

C_f = capacitance of the feedback-line capacitor.

Hence, beside the multiplication and addition an integration is performed now, too. This integration is based on the law of charging the capa-

citor so that it is necessarily effectuated on the basis of the real physical time (argument t in dt !) as an independent variable.¹⁸

¹⁸ The following relations, which can be found in every text-book on electricity, are valid for the process of charging a capacitor (Fig. 42a):

$$de_o = \frac{dq}{C}, \quad dq = i dt, \quad \text{and, for small values of } e_o, \quad ip = e_i,$$

$$\therefore de_o = \frac{i dt}{C} = \frac{e_i}{\rho C} dt, \tag{a}$$

wherefrom

$$e_o = \frac{1}{\rho C} \int e_i dt. \tag{b}$$

For the case of a series of input resistors (Fig. 42) (b) yields Eq. (25). The case in Fig. 42a is simple, whereas in Fig. 42 there is a negative feedback line so that a minus sign appears in Eq. (25).

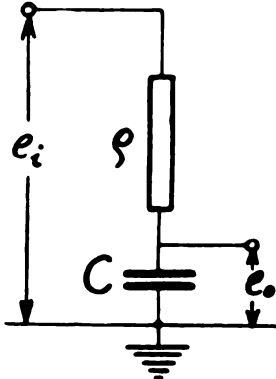


Fig. 42a

Relation (a) can be written also in this way:

$$\frac{e_i}{\rho C} = \frac{de_o}{dt} = \frac{d}{dt} \cdot e_o = p e_o, \tag{c}$$

where p is an operator, $p = \frac{d}{dt}$.

From (c) we obtain

$$e_o = \frac{e_i}{\rho C p}$$

which, for the case of a series of input resistors as in Fig. 42, yields

$$e_o = - \frac{1}{C_f p} \left(\frac{e_{i1}}{\rho_{i1}} + \frac{e_{i2}}{\rho_{i2}} + \dots + \frac{e_{in}}{\rho_{in}} \right). \tag{d}$$

(Minus sign in (d) is explained in the same way as earlier).

Since Z_{ij} is $Z_{ij} = \rho_{ij}$ (input impedances are invariably resistors), a comparison of the relation (d) with the general relation (23) yields

$$Z_f = \frac{1}{C_f p}$$

as an expression for the feedback impedance for the case of a capacitor in the feedback line.

If (d) be multiplied first by p , then by dt , and then integrated, Eq. (25) will be obtained. Therefore, comparing directly (d) with Eq. (25), the operator $\frac{1}{p}$ in (d) can be

recognized as meaning $\frac{1}{p} = \int () dt$.

Thus, Equation (23) may be considered as a general relationship valid for the scheme in Fig. 42, where, in the case of a resistor (R_f) in the feedback line (summation) applies $Z_f = R_f$, while — for the case of a capacitor (C_f) in the line mentioned (integration) — there is $Z_f = 1/C_f p$.

The integration, which is performed in the latter case, is effectuated on the basis of the real physical time. Therefore we may speak in this case of the „time-based“ integration and time-based integrators.

In our application, however, the independent variable is the geometrical displacement z of the abscissa-commanding elements r from the base line 0—0 of the instrument on.¹⁹

Therefore, an integrator offering relation

$$e_0 = -\frac{1}{C_f} \int_0^z \left(\frac{e_{t_1}}{\rho_{t_1}} + \frac{e_{t_2}}{\rho_{t_2}} + \dots + \frac{e_{t_n}}{\rho_{t_n}} \right) dz \quad (26)$$

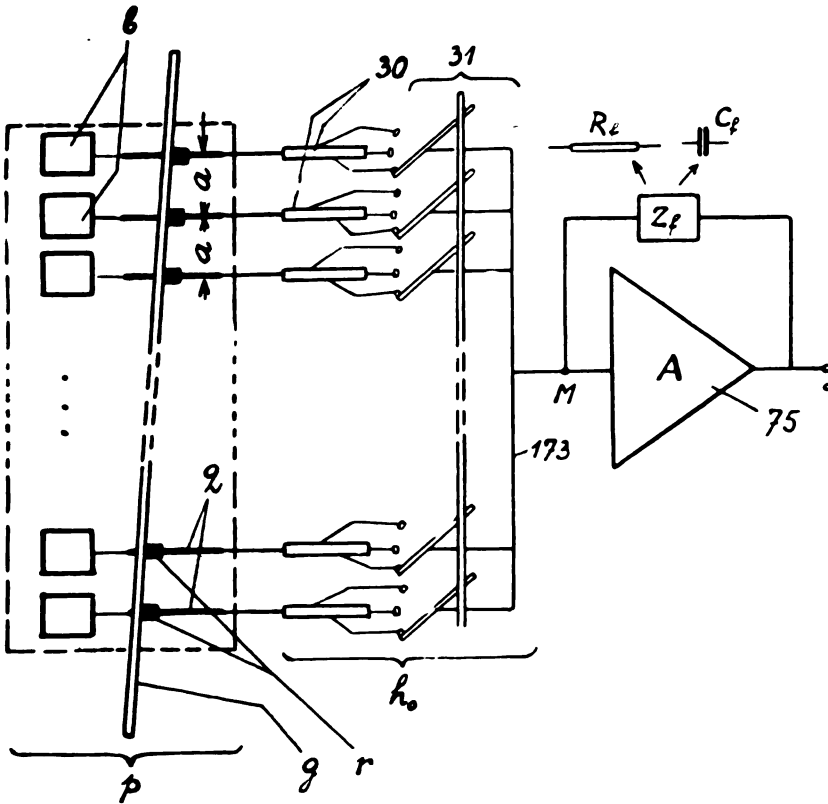


Fig. 43

as its operation equation would be quite appropriate in our application. For, relation (26) represents an integration based on displacement (argument z in dz). Relation (26) could be written as

¹⁹ If A_i , A_j and A_k curves are represented successively by function generators so that base line 0—0 of the instrument corresponds respectively to the axes x , y' and z' , the independent variables are respectively x , z' and y' . Nevertheless, since speaking quite broadly, we mention at this point only z as an independent variable.

$$e_0 = -\frac{1}{C_f} \int_0^z \left(\frac{e_{t_1}}{\rho_{t_1}} + \frac{e_{t_2}}{\rho_{t_2}} + \dots + \frac{e_{t_n}}{\rho_{t_n}} \right) \frac{dz}{dt} \cdot dt \quad (27)$$

where in the term

$$\frac{dz}{dt} = v \quad (28)$$

can be recognized the speed of the abscissa-commanding elements r . Thus we have

$$e_0 = -\frac{1}{C_f} \int_0^t \left(\frac{e_{t_1}}{\rho_{t_1}} + \frac{e_{t_2}}{\rho_{t_2}} + \dots + \frac{e_{t_n}}{\rho_{t_n}} \right) v \cdot dt \quad (29)$$

Relation (29) represents an integration based on time, which, as such, can necessarily be performed by a circuitry like that in Fig. 42.

This integration is simple if $v = v_0 = \text{const.}$ In this case v_0 is independent from t so that (29) yields

$$e_0 = -\frac{v_0}{C_f} \int_0^t \left(\frac{e_{t_1}}{\rho_{t_1}} + \frac{e_{t_2}}{\rho_{t_2}} + \dots + \frac{e_{t_n}}{\rho_{t_n}} \right) dt \quad (30)$$

The integration is rather complicated if $v = f(t)$, i. e., $v \neq \text{const.}$, for in this case v must remain behind the integral sign and match with the multiplication coefficients $1/\rho_{t_i}$ rendering them variable as well.

Thus we see that, *when using time-based integrators, a uniform speed of the water-line simulator is indispensable* if a simple integration operation is desired to be performed by our instrumentation.

Hence a two-integration variant of the instrument is also represented by Fig. 43. Only the impedance Z_f has to be realized by a capacitance C_f [$Z_f = 1/C_f p$; $1/p = \int (\) dt$] instead of by a resistance R_f ($Z_f = R_f$) and the restriction is imposed upon the speed of abscissa-commanding elements r which has to be uniform. (In the case of one-integration variant of the instrument — impedance Z_f formed as a pure resistance — there were no restrictions with regard to the function-generation speed).

The two-integration variant of the instruments as in Fig. 43 is again a concentrated integration variant. The earlier C. I. variant was mechanical (Figs. 35 and 36); this one will be spoken of as an *electronic C. I. variant* (for the amplifier is built up electronically; the variants which have no amplifier and are based on electricity, will simply be called *electrical*).

While with the mechanical C. I. instrument the speed of function generators was quite arbitrary (it could be variable and even both forward and backward movements were allowed within one run), the electronic C. I. instrument calls for a strict uniformity of speed. Hence it is more restrictive. (Restriction is due to the fact that the integration is based on physical time). In both cases, however, the speeds of all function generators (the speeds of forming abscissas of function generators) must be equal — this being a requirement resulting from the concept of the „concentrated integration“ (rule No. 1 of the C. I. instruments).

Here again it is worth pointing to the significance of the „*model of the ship in her environment*“ as the basis of the computer.

If the geometrical conditions of the model of the „ship“, i. e., the specific disposition of function generators' elements r are not fulfilled, then the model of the „environment“, i. e., of the water-line simulator, is of no use either. The model of the ship being quitted, every abscissa-commanding element r must have its separate driving device; no suitable application can be made of the water-line simulator as a unique and common driver for all the function generators in this case. For the purpose of compensating the loss of the water-line simulator a special control installation should be introduced to synchronize the work of the individual driving devices (with view of maintaining an appropriate position of abscissa-commanding elements r corresponding to a reasonable relation of the natural water line towards the ship).

Hence the elimination of the model disposition turns out to be very expensive. A number of separate driving devices and a special control installation³⁰ not only are costly, but also render the instrument very complicated

³⁰ The task of the control system should be, in the case of an oblique water line $0' - 0'$ (Fig. 38), to start individually, from the line $0 - 0$ on, the elements r at equal time intervals one after another and to keep their individual speeds both equal and constant.

In the case of a wave-form water line (Fig. 40 but with elements r at the line $0 - 0$) the order of starting the elements r would be more complicated. (These elements should also start from the line $0 - 0$ on).

In both these cases no mention has been made of the start from the line $0' - 0'$ on, it being supposed that the disposition of the paths of the elements r (distances a , ...) is irregular. This disposition is not equal to that of the ship sections represented by function generators, there is no *model of the ship* („geometrical component“ of the pick-up assembly is lacking), so that the starting disposition of the elements r , inasmuch as they are to start simultaneously, is not geometrically congruent to the form of the real water line. In other words, if there is no model of the ship, there is also no model of the water line, so that the elements r may start from a straight line, but with a very precise start timing which should be calculated before a run and accomplished during the run by a separate control installation.

On the other hand, if both the model of the ship and the model of the water line are established, there is no actual need either for individual driving or for time controlling, the water-line simulator g being both a very simple common driving device and a timing element at the same time.

and unexplicit. (Elimination of the water-line simulator means the elimination of the most natural analogy to the „ship's environment“, i. e., to the water line as its representative).

Multi — function-generator instrument with an arbitrary disposition of function generators' elements r („non-model instrument“) is beyond the scope of our discussion. (The so-called one-integrator optical variant, which will be discussed at a later stage, is, indeed, a non-model instrument, but it has only one function generator). Figure 43 relates only to the model instruments whereby the emphasis is laid on the model itself of the ship in her environment. This is the fundamental feature which makes Fig. 43 clearly distinct from the known right portion of that figure (Fig. 43 without p and $3I$). Indeed, in this variant only the pick-up unit p , the prescriptions for the water-line-simulator- g movement within it and the adjustment of multipliers h , h' and h'' (impedances Z_0) according to the model pick-up p are original, whilst the rest is borrowed. And the fact is significant that the importance of the idea of the „model of the ship in her environment“ and the disadvantageous consequences of its elimination have been illustrated just with such a variant which is nearest to the standard case, whereas the other variants present regularly a greater number of original features than this one.

Thus, once evidenced the importance of the model of the ship in her environment, the whole thing can be also viewed in the reverse direction: *Any general-purpose analog computer comprising some 20—30 function generators can be used as a ship analyzer when the pick-up assembly p is attached to it.*

In this case the connection of the pick-up assembly to the computer can be materialized in various ways (cables, linkages, connecting leads, etc.), which depends mainly on the type of function generators of the computer.²¹

The pick-up assembly itself can be materialized in very many ways. (For example, instead of being a bar, the water-line simulator g can be establi-

²¹ The fact that a common general-purpose analog computer can be converted into a ship analyzer (and vice-versa) is a very significant one.

Taking a general bird's eye view, the things stand like this:

Usually, general-purpose analog computers have a small number of function generators and a relatively large number of integrators (amplifiers). With the model ship analyzers we have a relatively large number of function generators, and, in the extreme case, only one integrator (see Figs. 43 and 73). The model pick-up assembly p , which can connect these extremities, lies between them.

The tendency to reduce the number of function generators of a ship analyzer leads toward the elimination of the simultaneous treatment of all the stations of a ship (breaking thus the very principle of model instruments) and, in the extreme case, results in a repetitive computer.

On the other hand, as from the very beginning on the ship is represented by a definite number of stations, hence by a *discrete sistem*, it is also the digital technique which intrudes itself upon the subject.

shed as a line of light with elements r sensitive to light, it can be even immovable with „paths“ bearing abscissa-commanding elements r movable, etc.). Nevertheless, *the model rule is established as soon as the „geometrical component“ is introduced into the pick-up assembly, i. e., as soon as the disposition (distances „a“ in Figs. 15, 57, etc.) of the elements determining the abscissas of function generators is the same as the disposition of the ship's sections of the real ship which are represented by function generators.*

Prior to the application of a general-purpose analog computer as ship analyzer block diagrams of the model ship analyzers (Figs. 56 and 57) should be taken into consideration as well as the „rules of the concentrated-integration instruments“.

Turning back to the scheme in Fig. 43 the following remark can be made:

The two-integration electronic C. I. variant illustrated in Fig. 43 is capable of evaluating only the values of A_k , $M_k(x)$, $M_k(y')$, $J_k(x)$, $J_k(y')$ from the fundamental problem No. 2, and D , $\mathbf{M}(x)$, and $\mathbf{M}(y')$ from the fundamental problem No. 1. (These are the values which are read before and just behind the integrators k and k' with the mechanical C. I. instrument, Fig. 36). To evaluate the value of $\mathbf{M}(z)$ and $\mathbf{M}(z')$ [or $\mathbf{M}(y')$ with the water planes represented by function generators], which — as is well known — offers a basis for the evaluation of the vertical moment of displacement, it is necessary to include a z -multiplier (z = displacement of the water-line simulator from the starting position) between the bus-bar 173 and the amplifier A of the instrument. This has been done with the scheme (block diagram) in Fig. 57 which will be discussed in more detail at a later stage. (See Chapter „Survey of Ship Analyzers“ and Appendix No. IV).

3) C. I. OPTICAL INSTRUMENT

a) BASIC PRESENTATION

Concentrated integration, applied to the I. I. optical variant, would result simply in a one-dark-camera instrument with which the second set of cardboards would be reduced to one or two fixed cardboards whilst the function cardboards (first set) would be made to pass successively through the dark camera. The short staying of each function cardboard in the dark camera (a subcycle) would be used for optical „reading“ and storing of the datum in a special storage unit (hence a feature of digital computers).

One passage of all function cardboards through the dark camera (one cycle) would result in storage units showing numerically each of the values D , $\mathbf{M}(x)$, $\mathbf{M}(y')$, $\mathbf{M}(z)$, A_k , $M_k(x)$, $M_k(y')$, $J_k(x)$, $J_k(y')$ depending on which kind of second cardboard and screen cardboard has been used in the run (cycle) under consideration. Hence, one set of ship-section function card-

boards is sufficient for the evaluation of all the results involved by the fundamental problems Nos. 1 and 2.

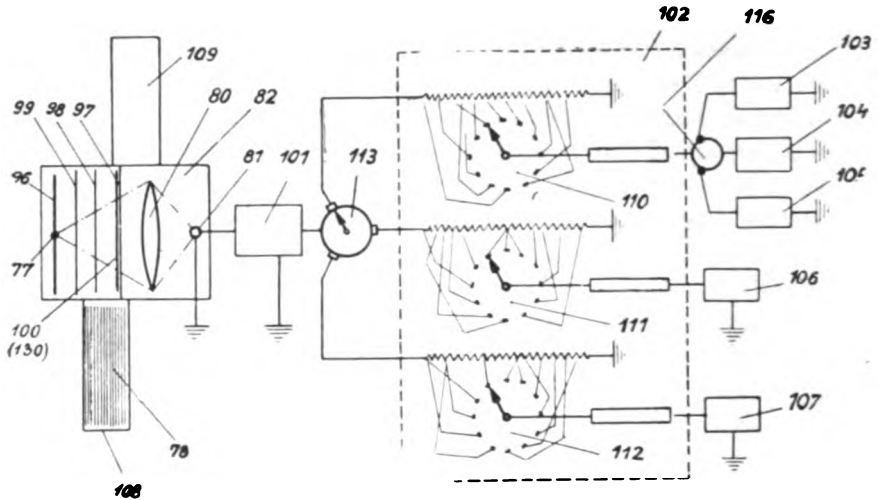


Fig. 44

77 — vertical light source; 78 — function cardboards; 80 — lens; 81 — photocell; 82 — dark camera; 96 — horizontal light source; 98, 99 — planes for triangle-forming devices (second cardboard); 100, (130) — screen cardboard (s); 101 — amplifier; 102 — multiplier unit; 103—107 — totalizers (storage units); 108, 109 — function-cardboard boxes; 110, 111, 112 — distributing valves of multipliers; 113 — distributing valve for multiplier's lines.

A general scheme of this instrument is presented in Fig. 44. The scheme is self-explanatory. It should be only said that there are 2 light sources (77 and 96) perpendicular to each other and two „second cardboards“ (in planes 98 and 99) which in fact are some kind of shutters (Fig. 45) forming triangles, these being generally perpendicular to each other. During a subcycle a triangle (or two) and the line light source which is perpendicular to the axis of symmetry 190 of the triangle engaged (Fig. 45) are active. Hence in this case the evaluation of y_0 and z_0 values (see Fig. 11) is made.

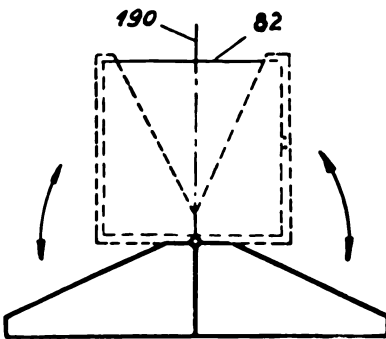
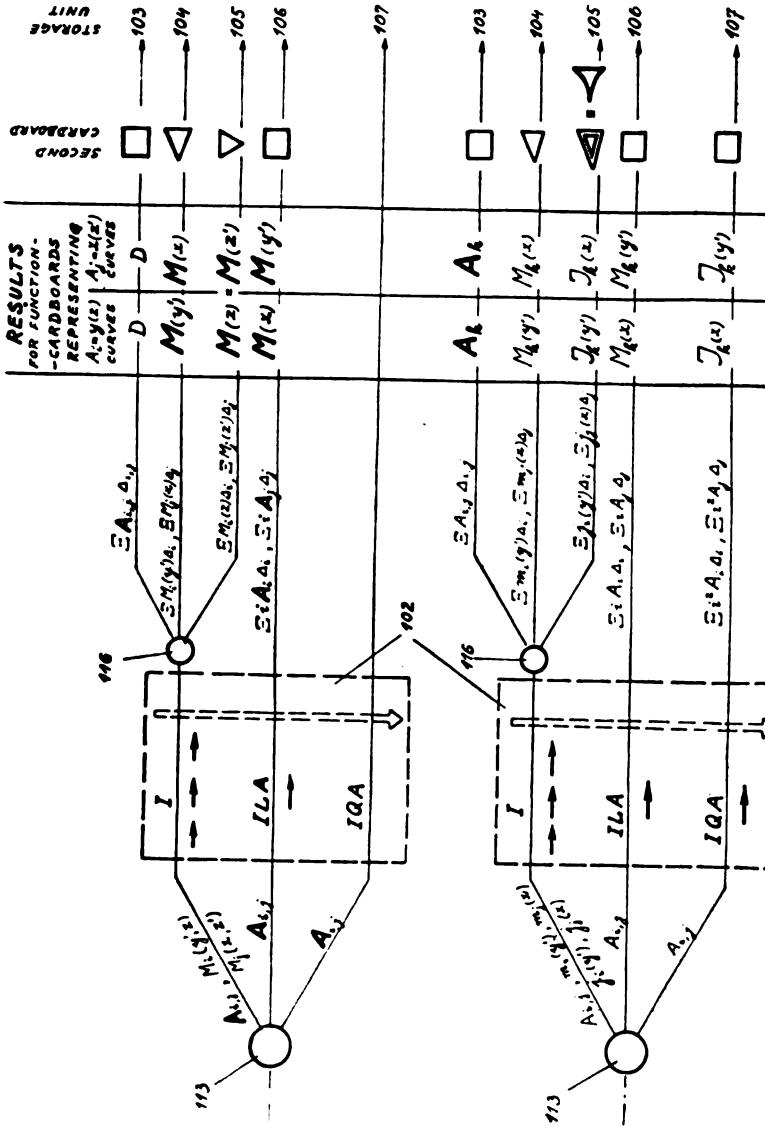


Fig. 45

Schemes in Figs. 46 and 47 give more details about the travel of the data within the fundamental problem No. 1 and No. 2 respectively. Horizontal arrows along the lines of the data travel mean the individual subcycles, while the vertical arrow across these lines represents a cycle. Squares under the heading „Second Cardboard“ mean



Figs. 46 and 47

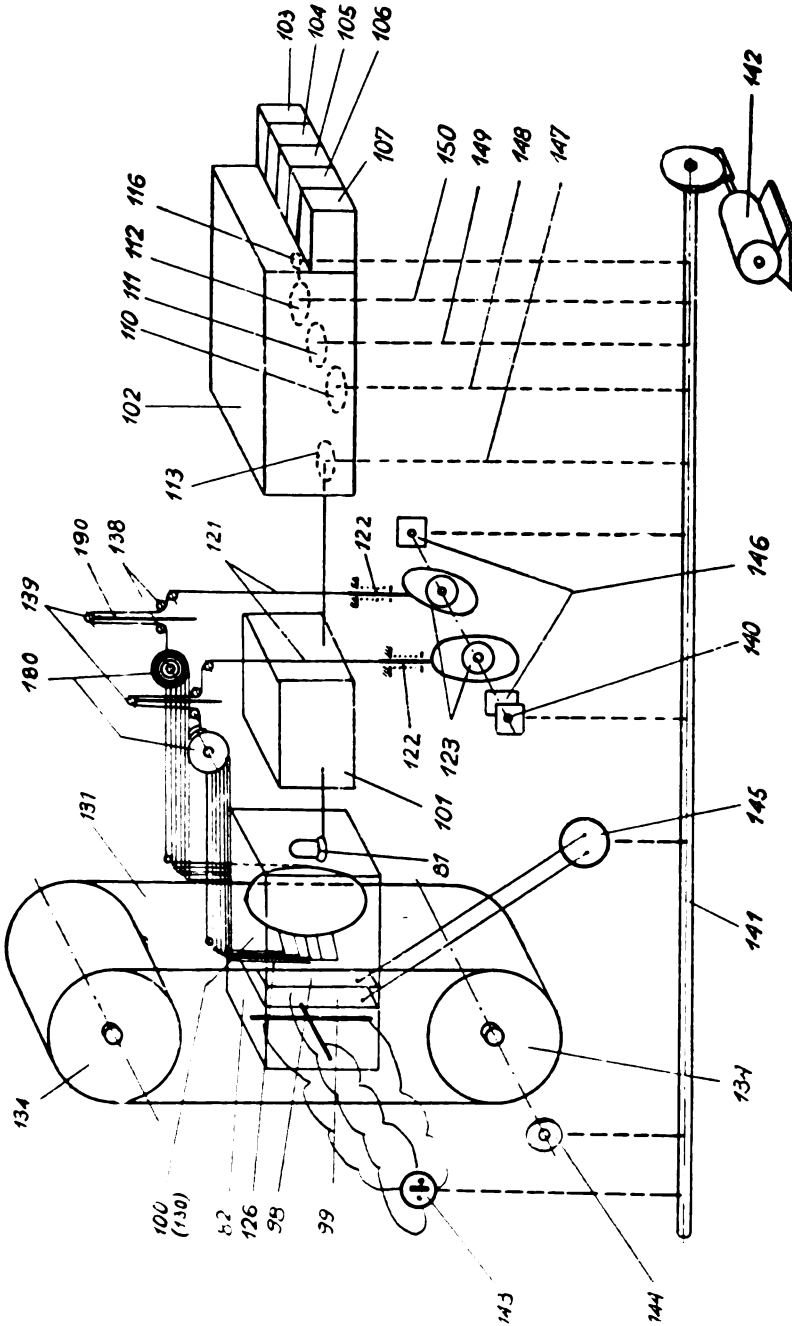


Fig. 48

121 — cable for screen-cardboard moving; 122, 123 — cam-rod and cam for moving screen-cardboard 100 (130) and sheets 126; 126 — sheets of translucent paper (serving for the simulation of the Smith effect); 131 — translucent paper for functions (ship's sections); 134 — drums for conveying 131; 138, 139 — cable; 141 — shortening device; 141 — main driving shaft; 141 — motor; 143 — light distribution (switch); 144 — steering of the driving of two-drum-134 complex; 145 — steering of the triangle-forming devices; 146 — steering of the driving of the cams 123 for producing wave or oblique water-line effect and for Smith's correction; 147 — steering of the distributing valve 113 to the three lines of the multiplier unit 102; 148, 149, 150 — steering of the distributing valves 110, 111, 112 respectively. Other designations as in Figs. 44, 50 and 51.

that the triangles are in neutral position. For the evaluation of $J_k(y')$ (on the basis of cross sections) two horizontal triangles or one quadratic-law-aperture cardboard (Fig. 47) are necessary.²²

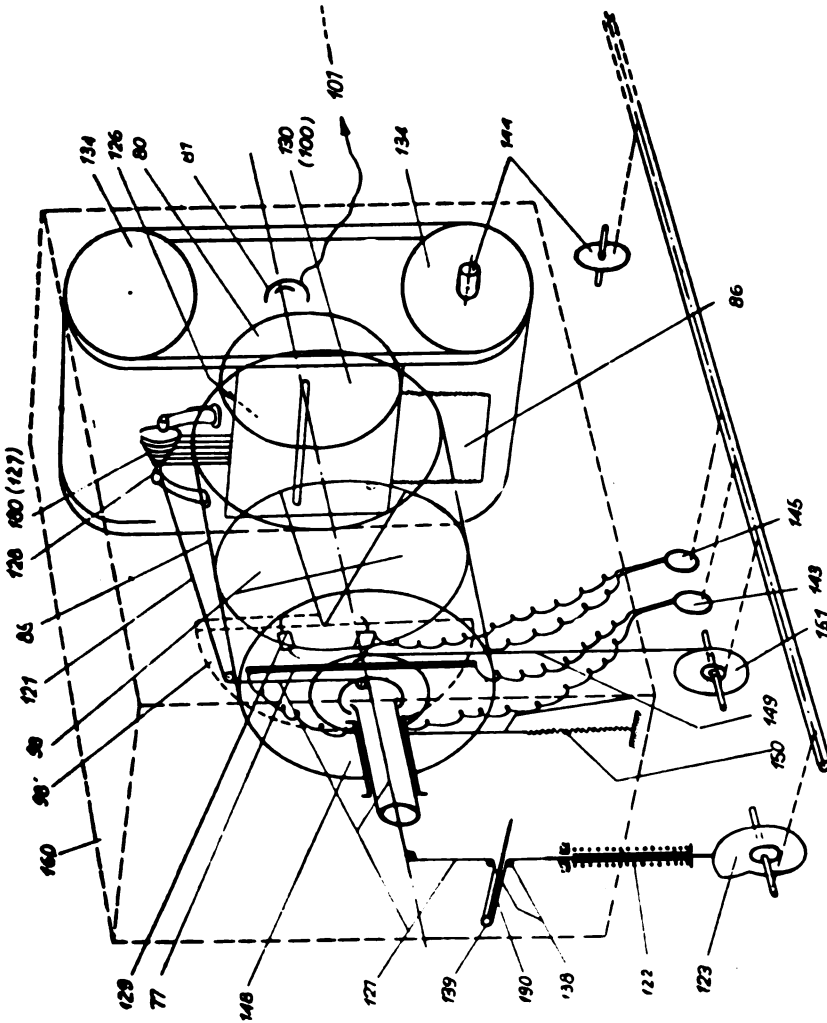


Fig. 49
 85 — drum (dark camera); 148 — bearing of the drum 85; 129 — triangle-98 activating device; 190, 151
 — steering elements for drum-85 turning; 160 — case of the instrument. Other designations as in Figs. 44,
 48, 50 and 51.

²² In Figs. 46 and 47 only the results are presented which are obtained on the basis of either cross sections or buttock-and-bow sections which are set by function cardboards. As a matter of course, the instrument can be also run on the basis of water-plane sections set by function cardboards.

A general view of this variant of instrument is given in Fig. 48. Designations are same as with Fig. 44. Instead of being cut in the function cardboards, ship sections are drawn on a strip of translucent paper which is then suspended on two drums 134 and made to pass through the camera 82. Steering mechanism is shown only schematically.

Fig. 49 represents a somewhat different variation of the pick-up assembly and steering mechanism of this instrument. In this case the dark camera is made as a drum 85 in which all dark-camera elements are situated. Rim (and slot) of the screen cardboard is steadily perpendicular to the light source; the axis of symmetry of the triangle(s) is perpendicular to the light source, too.²³ Drum 85 is revolvable about its horizontal axis (action of wheel 151 and spring 150), so that in this case the direct GZ-method is used rather than that of the evaluation of y_0 and z_0 .

In fact, many variations of this instrument can be evolved, but we shall not enter into discussing all of them here.²⁴

Wheels 138 and 139 with rod 190 (Figs. 48 and 49) serve for major variations of draft of the screen cardboards 100 (130) and sheets 126 between the cycles. Within a cycle that variation is performed by cams 123 and rods 122, hence automatically.

²³ Optical instruments in general are rather handicaped by *defraction error*. A narrow slot of the slot cardboard 130 which is used in the fundamental problem No. 2 is especially inconvenient in this respect. Therefore the variant of the pick-up assembly of the instrument as shown in Fig. 49 is more appropriate than that which is illustrated in Fig. 48. With the scheme in Fig. 49 the light source is steadily perpendicular to the slot of the screen cardboard so that the defraction error is less variable than in the case of the scheme in Fig. 48.

²⁴ A number of these instruments were patented in the period from 1956 to 1958. Several firms have considered the possibilities of manufacturing one or another variant of the patented analyzers (*A. J. Amsler & Co.* at Schaffhouse, Switzerland, *Siemens-Halske* and *Siemens-Schuckert*, Germany, *Lehmann & Michels*, Hamburg — Altona, Germany and others).

However, because of the poor interest on the part of possible buyers at that time (in 1956 and 1957 even existing digital computers were hardly, if at all, applied in European shipbuilding!), and an intensive occupation of the firms with the current production no ship analyzer could be put into production in the period mentioned.

This happened in spite of the fact that many outstanding technical authorities were quite in favor of ship analyzers. The experience with the firm *Lehmann & Michels*, Hamburg-Altona has been very characteristic in this respect:

The description of the above-discussed ship analyzers was submitted to Mess. *Lehmann & Michels* in February, 1957. The firm consulted two shipyards, *Germanischer Lloyd* (German Classification Society) and an Institute, all in Hamburg, who expressed themselves quite favorably as to the introduction of the ship analyzers („*Wir haben uns von hiesigen Werften, von einer Klassifikationsgesellschaft und der Hamburgischen Schiffbau-Versuchsanstalt Gutachten eingeholt und man hat uns übereinstimmend erklärt, dass eine derartige Einrichtung nützlich sein konnte*“ — quotation from the letter of the firm to the author, dated July 12, 1957).

The Institute (Hamburgische Schiffbau-Versuchsanstalt), to which the firm sub-

Since cams 123 are turned by step angle after each subcycle owing to which not only the draft of the elements 130 (100) and 126, but also their inclination angle φ are varied²⁵, this instrument offers a vast multitude of the positions of ship which can be calculated on the basis of only one set of function cardboards.

I) TREATMENT OF VARIOUS SHIP'S POSITIONS

In Table IV are shown the possible cases of the water line on the ship's plans, so that in the left column are to be found those referring to the longitudinal plan (L_i ; $i = 1, 2, 3, \dots$) while those relating to the transversal plan are presented in the right one (T_j ; $j = 1, 2, 3, \dots$). One position of the ship is represented by the pair ($L_i T_j$; $i, j = 1, 2, 3, \dots$). On the whole there are 9 interesting cases (see interconnecting lines between the position symbols in Table IV).

If we consider what kind of calculations one used to perform within the theory of naval architecture up to now, we shall see that there have been calculated only the positions $L_1 T_1$ (ship upright, curves of form), $L_2 T_1$ (trim, longitudinal launching and the like) and $L_1 T_2$ (heeling, stability curves at large angles of inclination and the like).

Yet the combination $L_2 T_2$, hence the trimming and heeling at the same time, seemed like a boggy to the calculators so that it has hardly ever been tackled (ref. [16]), and that in spite of the fact that the under-estimation of the trimming might lead to considerable errors when calculating the stability at large angles of inclination. The calculation involved by the $L_2 T_2$ position of the ship rendered this position too difficult to be considered, not to speak of the combinations $L_2 T_3$ and $L_3 T_2$ or even of the most complicated $L_3 T_3$ position.




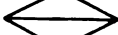


mitted the description for expert opinion on the usefulness and feasibility of the instruments, released a report whose main paragraph read:

„Den Vorschlag des Herrn Djodjo, ein Rechengerat für Schiffsentwürfe zu entwickeln, haben wir durchgearbeitet, und wir beurteilen diesen Vorschlag positiv. Die in der Arbeit des Herrn Djodjo beschriebenen Rechenoperationen müssen bei dem Entwurf eines Schiffes vom dem Konstruktionsbüro ausgeführt werden. Sie sind sehr umfangreich und erfordern eine beträchtliche Zeit. Es erscheint uns sicher, dass mit Hilfe des vorgeschlagenen Rechengerätes diese Zeit erheblich verkürzt werden könnte. Wir haben nicht geprüft, ob sich eine ausreichende Genauigkeit erreichen lässt, bzw. welcher Aufwand erforderlich ist, um eine ausreichende Genauigkeit sicherzustellen. Dieser Aufwand müsste so gering bleiben, dass sich der Ankauf des Gerätes für eine ausreichende Anzahl von Werften lohnt.“

(Quotation from the letter of Mess. Lehmann & Michels to the author, dated July 12, 1957).

²⁵ The above is valid for Fig. 48 where there are two cams 123. With the instrument in Fig. 49 the inclination is performed by revolving the drum 85, whilst the cam 123 regulates only the draft.

TABLE IV

WATER LINE ON THE LONGITUDINAL PLAN		WATER LINE ON THE TRANSVERSAL PLANE	
HORIZONTAL			HORIZONTAL
OBLIQUE			OBLIQUE
WAVE FORM			VARIABLE (OBLIQUE)

However, it is the latter position which is encountered in reality for the most part in the case of heavy seas and which should be the utmost desideratum in the ship's calculation.

Even the combination $L_2 T_2$ offers the possibility of, say, evaluating the stability curves for all the possible cases

$$GZ = f(D_n, \Theta_i, \varphi_j) \quad \left[\begin{array}{l} i, j = 5^\circ, 10^\circ, 15^\circ, \dots \\ D_n = 0,1D, 0,2D, 0,3D, \dots \\ D = \text{displacement} \\ \Theta = \text{angle of trim} \\ \rho = \text{angle of heeling} \end{array} \right] \quad (31)$$

for example for $[0,5 D, \Theta_{16}^\circ, \varphi = 0^\circ, 5^\circ, 10^\circ, 15^\circ, \dots]$, for $[0,7 D, \Theta = 0^\circ, 5^\circ, 10^\circ, 15^\circ, \dots, \varphi_{20}^\circ]$ and so on, rather than only for the position $[D_n, \Theta_0^\circ, \varphi = 0^\circ, 5^\circ, 10^\circ, 15^\circ, \dots]$ as it has been the case so far.

The combination $L_3 T_3$ (not to speak of the transient positions $L_2 T_3$ and $L_3 T_2$) offers a vast multitude of the cases and it is only the datum concerning the most unfavorable position of a ship obtained as a result of the elaboration of all the above cases which is needed to get a thorough insight into the stability of the given ship.

Indeed, in the latter case the dynamism of the behavior of ship in a seaway is preponderant, but the „static“ insight into the situation should not be neglected either.

II) ALLOWANCE FOR THE SMITH EFFECT

However, all the possible applications offered by this instrument have not as yet been demonstrated.

The ship once treated in the waves, it would be very useful to take into account Smith's effect as well.²⁶ And this instrument is highly suited

²⁶ The need for allowing for the Smith effect has been pointed out in a paper by Lj. Radosavljević (Ref. [14]).

in this respect. Here is the method: It is simply necessary to put a number of sheets 126 of translucent paper — see Fig. 50 — (or almost translucent, say, tracing paper) close to the plane 97 of the function cardboard and to lower them down at the linearly different drafts. Thus the light flux in the

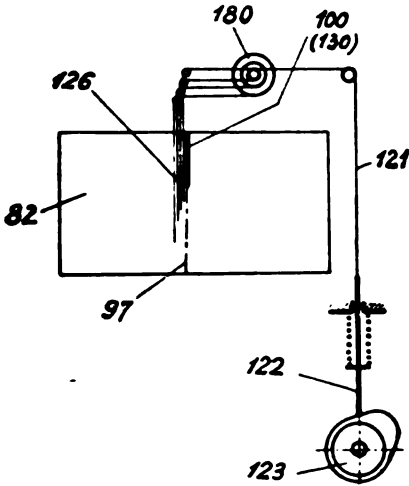


Fig. 50

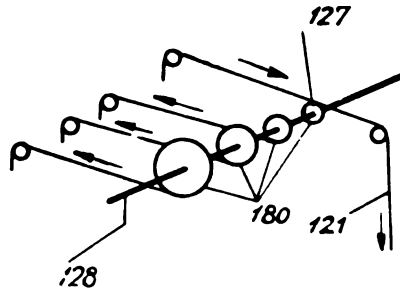


Fig. 51

regions nearer to the screen cardboard is bound to pass through a greater number of these sheets to reach the photocell, than in the case of the lower regions which are more distant from the screen cardboard.

Hence in this way the variability of the pressure within the wave is taken into account in a natural way (*water as fluid is substituted by the light flux as a kind of fluid*) and Smith's effect is allowed for automatically.

But, in order to bring the case into line with the standard trochoidal theory of waves, the lowering down of the sheets 126 beneath the edge of the screen cardboard 100 should be greater on the wave's crest than in its hollow. The regulation of this calls for a separate steering element.

This can be established in a very simple way according to Figs. 50 and 51. Cable 121 serving for connection between the screen cardboard 100 (130) and the cam-rod 122, is wound on the wheel 127 (Fig. 51). On the shaft 128 of this wheel a series of other wheels 180 of linearly different diameters are mounted. Each of these wheels is connected by a separate cable to one of the sheets 126. Thus between the cam-rod 122 and the shaft 128 there is only one cable and from the shaft on as many of them as there are sheets 126 plus one for the screen cardboard. The sheets 126 are provided with the weighty elements, traversings, etc., so that they will follow the

screen cardboard *100* completely with respect to its obliquity. Owing to the specific way of winding the cables on the wheels of the shaft *128* (cable for the screen cardboard gets off the wheel in the upper portion of the wheel, whilst other cables do that in the lower one) the sheets *126* will be lowering down while the screen cardboard is being raised and vice versa, and that is just what was desired.

III) COMPARTMENTATION AND DAMAGED-STABILITY CALCULATIONS

A further admirable possibility offered by this instrument is that of treating compartmentation and damaged-stability calculations according to the real permeabilities of each of the compartments rather than on the basis of the global permeability coefficients for each of the compartments as a whole.²⁷

To achieve this, it is simply necessary to make the function cardboards (say, for cross sections) relating to a certain number of sections of the compartment under investigation whereby the surfaces occupied by the bulky things like boilers, engines, load, tanks, etc., will be preserved as valid for displacement, whilst the other portions of the sections will be obliterated. (The surfaces to be obliterated will be blackened by Indian ink if the translucent papers are used as function cardboards, and they will remain uncut if the cardboards, tin plates and so on are used as function cardboards).

The function cardboards so prepared are inserted in the right place in the normal series of function cardboards and then the instrument is run in a normal way. By trial-and-error procedure, hence by a series of super-cycles, the equilibrium position will be found before long, i. e., the water line will be reached which in general will be both trimmed and heeled and will fulfil the equilibrium conditions. Hence this is a typical „indirect“ problem like that of the wave location on the ship.

* * *

In summary, it can be stated that the one-dark-camera optical instrument (concentrated-integration optical instrument) with an adequate steering mechanism seems to be one of the most promising ship analyzers.

As a matter of fact, the one-dark-camera optical instrument is the only one of the described instruments which is not a model instrument. It is not based on a geometrical disposition of function generators or their

²⁷ This evidently leads toward the elimination of the concept of „floodable lengths“ and allied methods of calculation.

abscissa-commanding elements r and thus there is no water-line simulator to actuate all the function generators at the same time. Time deconcentration calls for storage units so that the instrument takes on some features of digital computers.

4) BUSAC

Before entering into a survey of all the variants which have been discussed or just mentioned in this context, let us familiarize with BUSAC, which, as the author is aware, is the only ship analyzer existing so far. BUSAC (= **B**ureau of **S**hip **A**nalog **C**omputer) is an instrument, developed in U.S.A. (Ref. [10]), which covers almost the same field of calculation as our instrumentation.

BUSAC has a clear plastic drum 152 (Fig. 52) which is revolved by a motor at 60 rpm. On the inside periphery of the drum a transparent paper 153 (Fig. 53) is placed on which a series of ship's cross sections (due to the symmetry only one half of each section) is traced as an opaque black line 154 (see Fig. 53). Cathod tube 155 emanates a beam of light which passes through the lenses 156 and plastic drum 152 and strikes the curved mirror 157 which is focussed on the photocell 158. Control unit 159 of the photocell circuit causes the voltage of this circuit to vary in such fashion as to keep the light beam riding on the edge of the opaque black line 154.

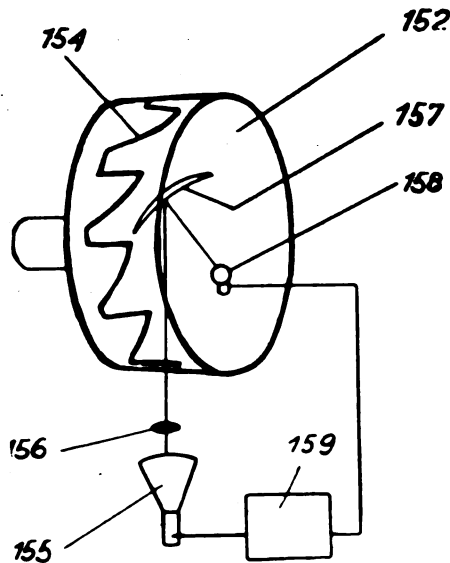


Fig. 52

Hence the photocell voltage is proportional to the ship-section functions and is generated by the photoformer technique.

Another channel similar to the one shown in Fig. 52, which is acting in synchronism with the former one, provides a control function (voltage). This function limits the ship-section functions from station to station and so the water line is „set“.

Hence both channels are actually function-generating units. (Broadly speaking, the former corresponds to the assembly c of function generators,

whilst the second relates to the water-line simulator g with our instrumentation). Basis (abscissa) is real physical time, so that, for securing the right „interplay“ of their voltages, these channels must be strictly synchronized. Besides, for the purpose of control over a long period of time a separate control circuit must be included.

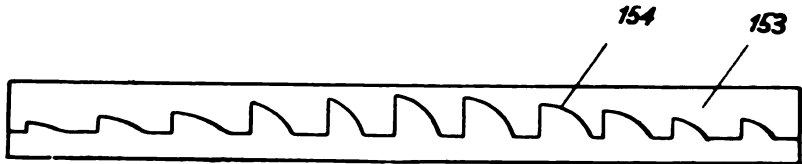


Fig. 53

The voltages generated in this way are transmitted to a number of adders, subtractors, multipliers, integrators, amplifiers, etc., (see block diagram in Fig. 59) in order to obtain all the values covered by the fundamental problems No. 1 and No. 2.

The substantial difference between the model variants of ship analyzers and BUSAC is that with the former instruments, since they are based on the model conception, all the stations are treated simultaneously, whereas with BUSAC a successive (but a very fast) treatment of stations is performed. Thus BUSAC appears to be also a non-model instrument.

Photoformer technique is not capable of a very precise function generation (Ref. [13, p. 152]). Nevertheless, the accuracy of the results obtained by BUSAC is sufficient for practical purposes (Ref. [10]). At a later stage, BUSAC has been used as a basis for the development of another machine which operates from analog inputs but computes with digits so that its accuracy is extremely high (Ref. [12, p. 330]).

D) GENERAL SURVEY OF SHIP ANALYZERS

In order to obtain a survey over all the discussed instruments, block diagrams have been drawn in Figs. 54 through 59 for the main types of the instruments. Model variants are represented by Figs. 54, 55, 56, and 57 whereby one-integration instruments, I. I. instruments and C. I. ones (Figs. 56 and 57) are represented respectively. Figures 58 and 59 relate to the non-model instruments representing respectively one-integrator optical instrument and BUSAC.

In these diagrams the following designations are used:

b (vertical rectangle) means function generator in general (mechanical function generator with tape, cam, etc., tapped potentiometer with wiper, diode function generator, dark camera with cardboard and so on).

r (small black rectangle) means abscissa-commanding elements of function generator in general.

k*, *k'* and *l (circles) mean integrators not working on the basis of time (ball-and-disk integrator, double-ball integrator, friction-cone integrator, etc.) which can be either constructionally fixed to the function generators or only schematically attached to.

k*, *k' (triangles with feedback line) mean integrators working on the basis of time (d-c amplifier with feedback loop including capacitor)

h (horizontal rectangle) means multiplier-adder adjusted to integration coefficients — I-series.

h' (horizontal rectangle) means multiplier-adder adjusted to linear lever-arm coefficients — ILA-series.

h'' (horizontal rectangle) means multiplier-adder adjusted to lever-arm coefficients squared — IQA-series.

(Hence the latter three rectangles may mean a loop-belt differential, an electrical scheme for multiplication and addition., etc.).

g means water-line simulator of any type.

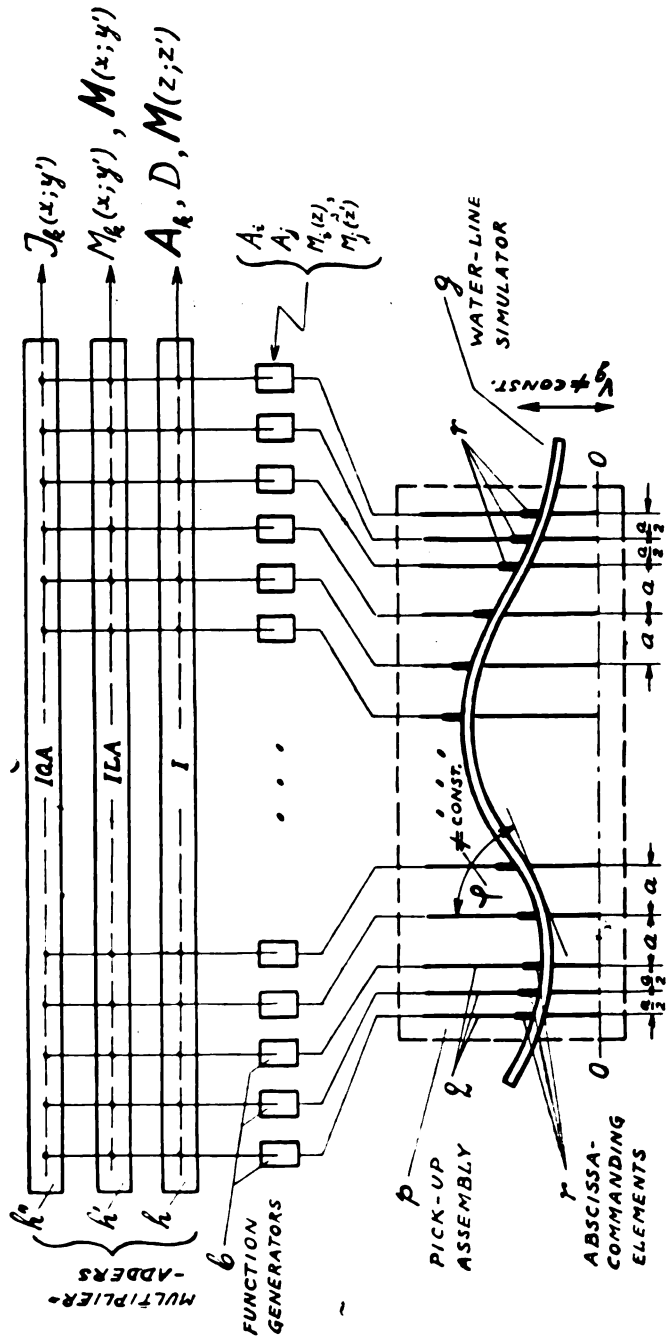


Fig. 54

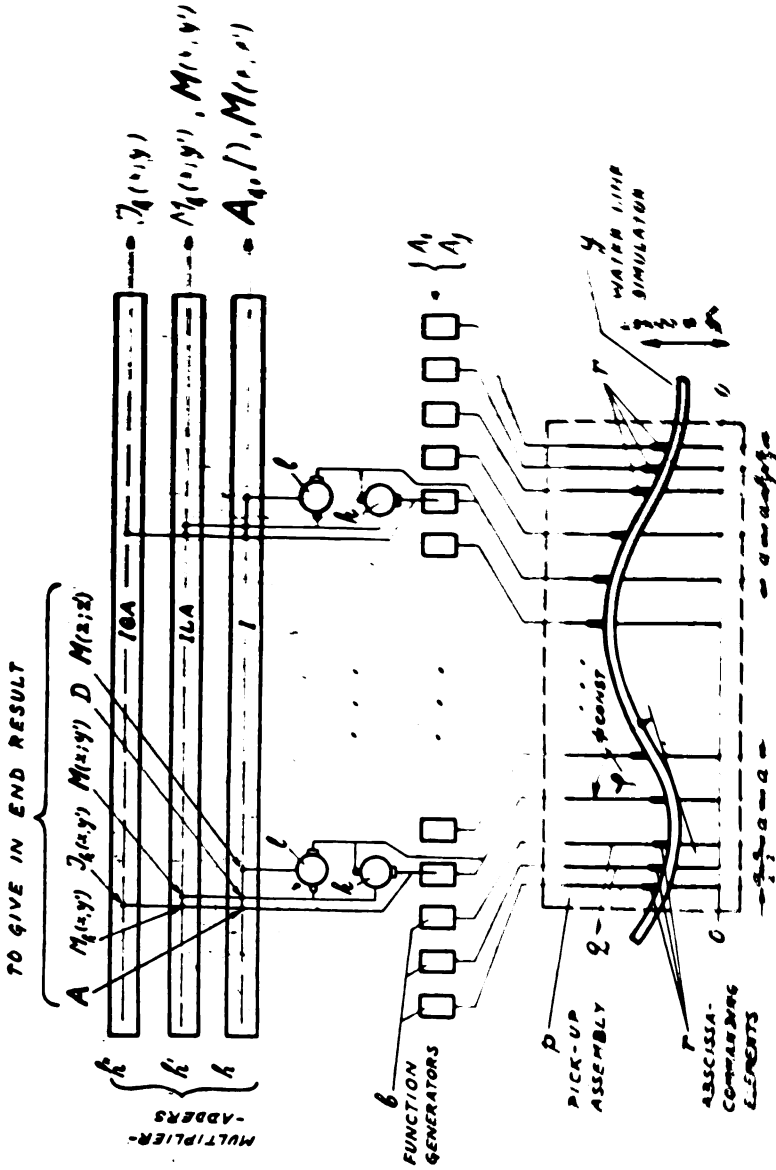


Fig 55

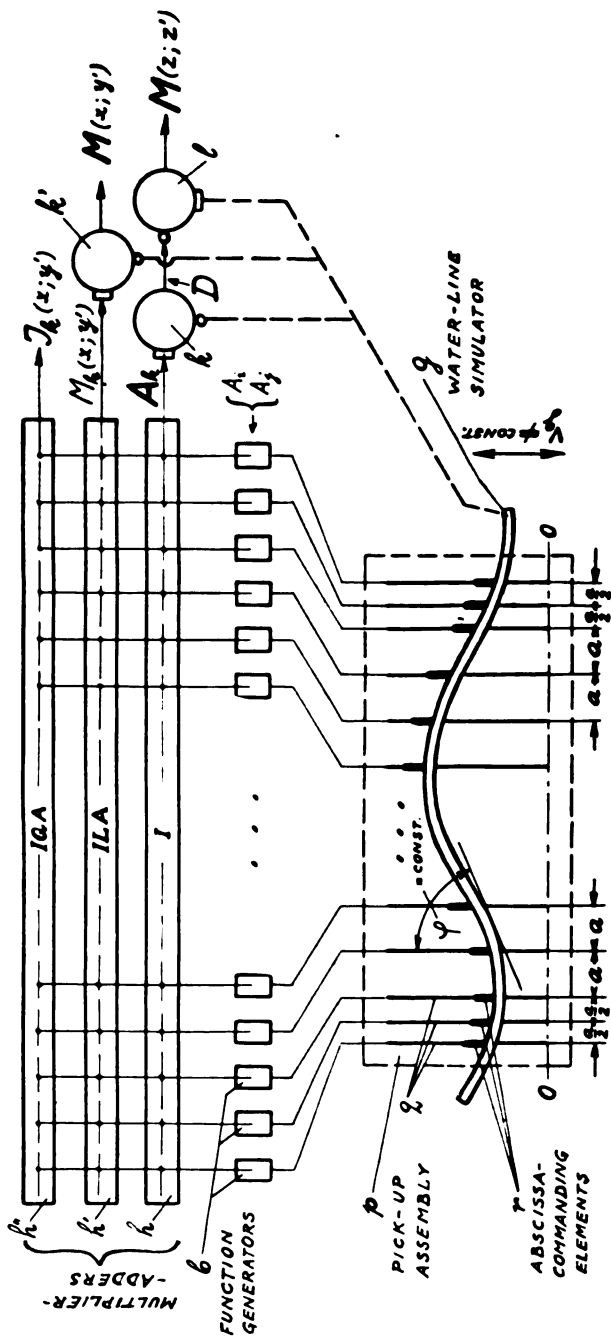


Fig. 56

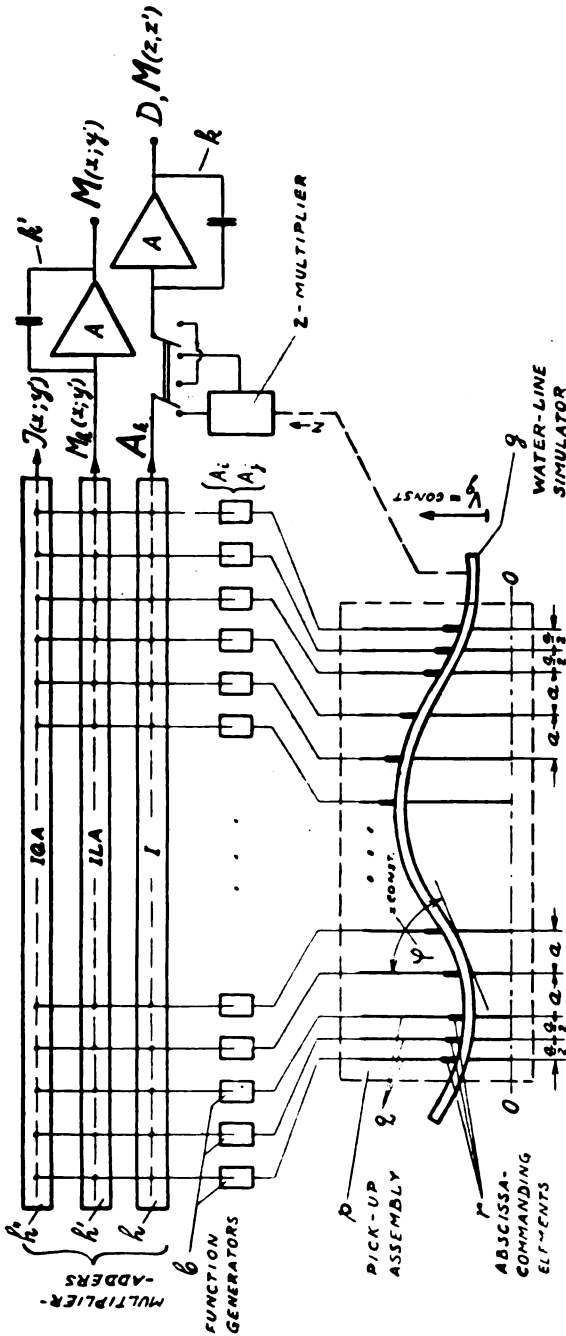


Fig. 57

Distances „a“ — indicating either the disposition of function generators b as such or that of their abscissa-commanding elements r only — form the basis of all these instruments. This basis, representing the ship under consideration, is completed by the water-line simulator g representing the

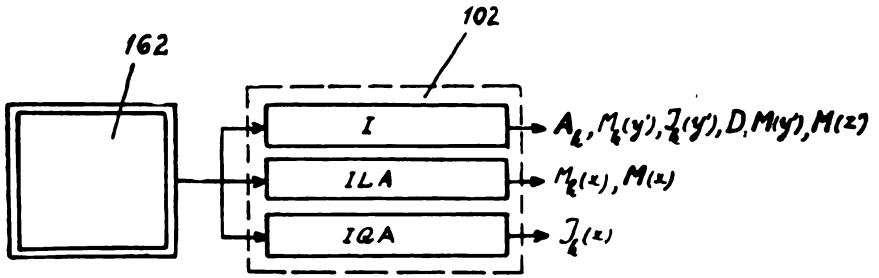


Fig. 58

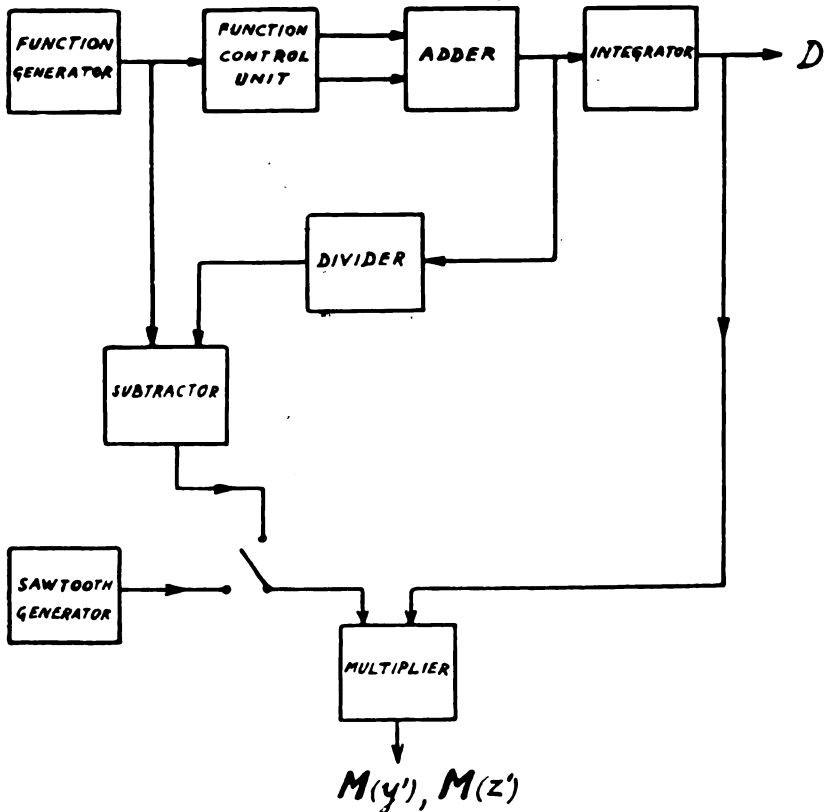


Fig. 59

environment of the ship. Correct correlation between the „ship“ and her „environment“ is provided just owing to the right disposition of the elements mentioned. Besides, the adjustment of the multiplier-adders is directly dependent on this disposition (lever-arms, integration coefficients).

Fig. 54, representing the one-integration instruments, shows how the data picked up from the function generators are directly transmitted to the multiplier-adders h , h' and h'' .

In this case only the second integration [the one represented by the symbol Ξ in (4) and (5)] is performed by the instrument. The results of the first integration [symbol \int in (4) and (5)] are calculated in a classical way and set into the instrument as input data.

Fig. 55, representing the individual integration instruments (I. I. variants), shows how function-generator data are first made to pass through the integrators k and l and only then are delivered to the three multiplier-adders h , h' and h'' . The integrators k and l receive thereby the data on the displacements of the abscissa-commanding elements r , too. Basically, they are connected as shown in Fig. 29.²⁸

I. I. instruments as shown in Fig. 55 perform two integrations (Ξ and \int), but, as a large number of integrators are required thereby (two integrators for each station), they turn out to be rather inappropriate.

Fig. 56, representing concentrated-integration instruments (C. I. variants), shows how the data picked up from the function generators are transmitted first to the multiplier-adders h , h' and h'' and only then to the integrators. The integrators are fed also by the datum on the displacement z of the water-line simulator, i. e., on the displacements of the abscissa-commanding elements r which are equal now for all these elements and therefore are delivered from the water-line simulator directly.

Fig. 57 represents concentrated integration instruments (C. I. variants) with the integrators working on the basis of time. This is a special case of the instruments illustrated in Fig. 56. Restrictions due to the basis of integration (time) involve some more restrictions with the instruments in Fig. 57 in addition to those valid for the instruments in Fig. 56.

Restrictions regarding the angle of the water-line simulator towards the paths q of the elements r (constancy of the angle within a run) are imposed on the C. I. instruments (Figs. 56 and 57) and that for the sake of reducing

²⁸ Optical I. I. instruments and those with time-based integrators are not represented by Fig. 55.

the number of integrators. That is just the reverse case as compared with the I. I. variants where there are a number of integrators and no restrictions with regard to the water-line simulator's position. However, as the C. I. instruments require quite a small number of integrators for performing both integrations (Ξ and \mathcal{J}), they appear to be very practical.

In Fig. 56 we see the interconnection lines between the integrators and the water-line simulator g by which the transmission of the datum concerning the water-line simulator's displacement is designated. With the integrators based on time there is no need whatever for these lines: With the instruments in Fig. 57 the displacement z of the water-line simulator is computationally converted into the physical time, and the time is delivered to the integrators „by itself“, so that the interconnection lines become needless. Of course, physical time necessarily „passing in accordance with linear law“ (speed constant), the water-line simulator must behave in the same way, otherwise the substitute (physical time) will not correspond to the original (simulator's displacement). This appears to be a new approach leading to the conclusion that the speed of the water-line simulator's displacement must be uniform when the integrators based on time are used

And this is the additional restriction valid for the instruments in Fig. 57 as against those in Fig. 56: Whilst in Fig. 56 the water-line simulator's speed and direction can be changed during a run, in Fig. 57 both the speed and direction must be constant. In both cases, however, only translation is allowed for the water-line simulator ($\varphi = \text{const}$).

A further difference between Fig. 56 and Fig. 57 is that the integrator l fails in the latter figure. Instead of that, a z -multiplier is included between the multiplier—adder h and the integrator k in Fig. 57.

The integrator l receives (Figs. 36 and 56) the function at the abscissa input and the abscissa at the ordinate input. And in the case of Fig. 57 the function which should be received by it is the displacement of ship, which, plotted against the draft (water-line simulator moves uniformly in Fig. 57 and corresponds to the draft), is not a linear function.

Therefore, since an integrator based on time can receive at its „abscissa input“ only a linear function (physical time), the integrator l — conceived as an additional integrator to the integrator k (Fig. 56) — is unacceptable in time-integration scheme in Fig. 57. It is omitted and, in order to perform the operations indicated by the right-hand side of Eq. 21 [with $s = 1$ for the purpose of obtaining $\mathbf{M}(z)$], we see that the output of h must first be multiplied by z and only then delivered to the integrator k for the purpose of obtaining $\mathbf{M}(z)$ as the output of the integrator.

The z -multiplier is materialized as a potentiometer multiplier whose wiper is ganged with the water-line simulator g (Fig. 57). It is used only in the run No. 3 (evaluation of $M(z)$, see Table III). Its connection to the computer is presented in more detail in Fig. 73 (switch N).

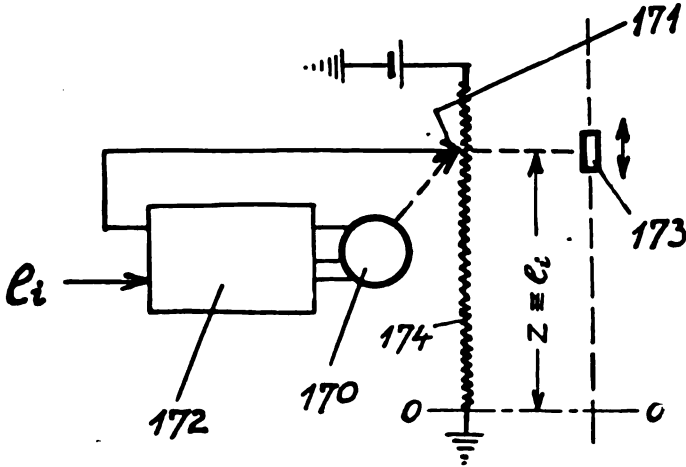


Fig. 60

For a further comparison of Fig. 56 and Fig. 57 see Appendix III.

Hence the block diagrams in Figures 54, 55, 56, 57 cover the whole range of the model instruments. They involve all the model instruments without specifying any of them explicitly.

As these diagrams refer not only to purely mechanical, electrical, optical, etc., instruments, but also to their combinations, the following should be pointed out: If mechanical displacements are to be transformed into electrical units, that is mainly performed by means of the linear potentiometers. If the reverse is the case (electrical units to be transformed into mechanical displacement), then standard use of positioning servomechanism is made whereby a servomotor 170 (Fig. 60) adjusts the wiper 171 of the follow-up potentiometer 174 so that it picks up the voltage equal to the input voltage e_i to the mechanism. An error-sensing device 172 compels the motor 170 to perform that and thus the input voltage e_i is transformed into the geometrical displacement z ($z \equiv e_i$) of the slider 173 which is ganged with the wiper 171 of the follow-up potentiometer.

Fig. 58 represents the block diagram for the C. I optical instrument (one-integrator instrument). By 162 (double rectangular) Gray's modified

integrator is designated which is both a function generator and integrator. Multiplier is designated by 102; the results of both fundamental problems are read at the end of the 3 lines of the multipliers (I, ILA and IQA lines).

Fig. 59 represents the block diagram for BUSAC and that only for the program of one portion of the fundamental problem No. 1 [D , $M(y')$, $M(z')$]. A similar arrangement is set up when the fundamental problem No. 2 and other problems are programmed (Ref. [10]).

C. I. optical instrument and BUSAC are also two-integration instruments.

In both Fig. 58 and Fig. 59 amplifiers, switches, steerings and other secondary elements have been omitted for the sake of clarity.

E) CONCLUDING CONSIDERATIONS

Analog computing instruments which have been discussed in this paper are called „ship analyzers“. Needless to say, all ship analyzers presented or only mentioned here are not equally suitable for realization. But it is also difficult to say which of the instruments discussed would prove the most adequate constructionally and operationally.²⁹

Therefore, leaving alone the question of the choice of a variant, let us see how the establishment and adoption of presumably successful ship analyzers would affect techniques and methods applied in naval architecture and shipbuilding industry. In order to realize this it is necessary to confront the present situation with that which would possibly arise with the introduction of ship analyzers (or with a broader application of digital computers in this field as well).

The present state is as follows: It is estimated that for the elaboration of the problems to be treated by ship analyzers (see page 2) some 150 to 500 effective working hours are necessary per ship if conventional auxiliary aids and methods are applied (slide-rule, planimeter, desk machines, tabulation methods, etc.). In case of some war ships this figure might be much higher.

However, by introducing the presented ship analyzers only a couple of hours would be quite sufficient for the elaboration of the whole scope of problems mentioned.

Hence calculations which with the classical methods took one or more *months* of tedious work could be performed by means of a ship analyzer in but a *couple of hours*. Moreover, most of the present methods necessarily call for the engineer's precious working hours, whereas a ship analyzer can be operated by less skilled manpower. And if we bear in mind great possibilities offered by ship analyzers in theoretical work in naval architecture we can realize that these instruments will prove to be quite *revolutionary* in

²⁹ It is an old truth that the way from the starting idea to the final design is sometimes rather long. Moreover, engineering requirements may render a relatively good starting idea thoroughly unacceptable in the final design. Therefore, although a comparative analysis of the instruments outlined would be very interesting at this point, we shall nevertheless refrain from such an analysis for the time being.

their field of application in both *quantitative* (time saving) and *qualitative* (new fields for investigation) respect.

This fact was brought to light at the Annual Meeting of the Society of Naval Architects and Marine Engineers held in New York, November 9—12, 1955, when, on reporting on BUSAC, the first and the only one known „ship analyzer“ as yet, some of the people present openly expressed the same opinion as above. [Capt. R. L. Evans, USN, Member: „*This paper* (on BUSAC, — remark by B. Dj.) *probably marks the opening of an era in naval architecture...*“, Ref. [10, p. 384]].

A new instrument of such efficiency employed in the designing offices and shipyards is bound to bring forth some quite new features in this sphere:

1) By considerably reducing the time required for one of the most important stages in designing a ship, a saving in time needed for the construction of a ship may be achieved.

2) A possibility of certain improvements in ship construction is obviously offered. As a matter of fact, it often happens that designers submit a design variant to the works although they may have eventually come to a conclusion that by some minor modifications a better solution could be arrived at. With time being restricted and with their reluctance to go over the same tedious procedure of calculation, designers are bound to face the situation just described. But with such an instrument at hand, they would evidently more readily make up their mind to tackle some other variants as well and so finally to reach a more perfect solution. Improvements in ship construction are achieved thereby not only through elaborating a larger number of design variants but also owing to the fact that a naval architect, once released from tedious repetitive calculations, can employ his talents more conveniently for solving difficult problems which call for creative efforts.

3) A broader adoption of Russo's diagrams (or whatever they might be called, and whatever might be applied in lieu of them) is well secured owing to the very easiness with which they can be obtained by these computers. These diagrams being very useful to captains, some navies have introduced them as obligatory throughout the fleet (Italian navy). This has been done with an obvious view to improve the security of ships and that of navigation in general. The difficulty involved in elaborating these diagrams is the only reason why they have not been adopted more extensively so far.

4) The possibility is also offered to improve the accruacy to which the problems treated by these instruments can be solved. This is due to the fact that a larger number of points and denser sets of resulting curves are to be arrived at now. Besides, a great advantage is offered by the fact that

with the application of the instruments human errors are eliminated almost entirely.

5) The easiness with which once very tedious and time-consuming calculations can be performed by these instruments offers new possibilities in research institutes, towing basins, etc., of investigating the influence of various factors on the efficiency of ships and of making comparative analyses and the like. New fields of calculation such as compartmentation calculation on the basis of real permeability, automatic calculation of the Smith effect, possibilities for the calculation of the most versatile positions of a ship, etc., hence almost all the problems which can be approached only after the introduction of these modern computers, — represent a warrant of the further development of the theoretical aspect of the theory of naval architecture as well.

Beside these major features which would be brought forth by ship analyzers, there is a series of minor ones, but it is out of place to discuss them here.

To sum up, one may say that the application of ship analyzers would exert a considerable influence in many fields — designing, industry, navigation, science, etc.

In the end, without entering into the „old“ digital-versus-analog dispute, let us consider here another aspect of the interrelation of the two types of computers when applied in naval architecture. This, at the same time, would provide an answer to the question: Why build new (analog) computers, if there are already digital ones?

As to the capability of a majority of electronic digital computers to deal with the problems treated here by our ship analyzers, the answer is surely positive. These are very universal machines with a wide range of application and very high accuracy. But, their universality is reached at the expense of their being rather bulky, too expensive and requiring a highly specialized personnel.

Ship analyzers, hence analog computers as they are conceived here (specialized computers, no general-purpose machines) are, on the contrary, rather small, relatively simple and therefore incomparably cheaper. Besides, the elements of ship analyzers are surely much easier to understand for a naval architect (especially model instruments) than the complicated structure of a digital computer.

As such, ship analyzers can be easily brought into the „first trenches“, i. e., made available for naval architects even in the smallest shipyards, for private consulting naval architects as well as for small designing bureaux, etc.

Big digital computers, on the contrary, can be employed only by highly selective users. Therefore they have been recommended to be used

in computing centers to each of which a series of shipyards, designing offices, institutes, etc., should be attached (Ref. [11]). As a matter of fact, some centers of this kind have recently been established in Denmark and Sweden (Refs. [21], [23]).

But a very important fact has been overlooked as regards calculating centers. Namely, the fate of most centers is to be overburdened with a variety of problems which must be solved concurrently. And if designers are obliged to send tidily classified data to a distant calculating center and possibly to wait for their turn to come, and only to be able to see whether their design variant is good or bad when the whole material comes back, it is sure they will elaborate fewer variants than if they are independent. With the calculating centers all the excellent properties of modern digital computers are obliterated merely by the waste of time due to these „aller et retour“-s, not to speak about the disadvantage of the designers themselves not being able to take part in the calculation process nor about other inconvenient features involved (confidentiality?).

The case of ship analyzers is just the reverse of that of the digital computers and calculating centers involved thereby. Being relatively simple, small, cheap, etc., they can be within reach of the user's hand. Provided with such instruments, designers become independent. They will surely more easily tackle a new variant, starting now from their own data, which do not require any special classification whereas in the case of digital computers a tidy classification and enlisting data for sending them to the calculating center takes possibly as long as is required for the elaboration of one more series of design variants by the ship analyzers.

Hence the modern digital computers are by no means in the way of ship analyzers. Just the reverse is the case: Some inadequacies of these computers call for the introduction of small analog computers such as are our ship analyzers. Thus all the efforts and interventions made in connection with the introduction of the modern computing techniques in ship calculation must be viewed as paving the way directly for both digital and analog computers rather than only for digital ones. And both these techniques will surely find their place in this field of application — each in its specific way — as, for the rest, the case has been in the other fields, too.

Hence the fact that so far mainly digital computers have been used in this field should by no means lead to the wrong conclusion that analog computers have nothing to do there. On the contrary, this field is widely open for the application of the latter instruments, as we have just seen. To make it clear and to indicate the way in which this field can also be approached by analog computing techniques — has been one of the main objects of this paper.

F) APPENDIXES

APPENDIX I

Although mechanical solutions are scarcely encountered in modern computing techniques, we shall discuss the already mentioned mechanical steel-tape function generator in more detail here. As a matter of fact, this generator can easily be converted into an appropriate electrical generator for generation of monotonic-curve voltages and that is why we are going to consider it more fully.

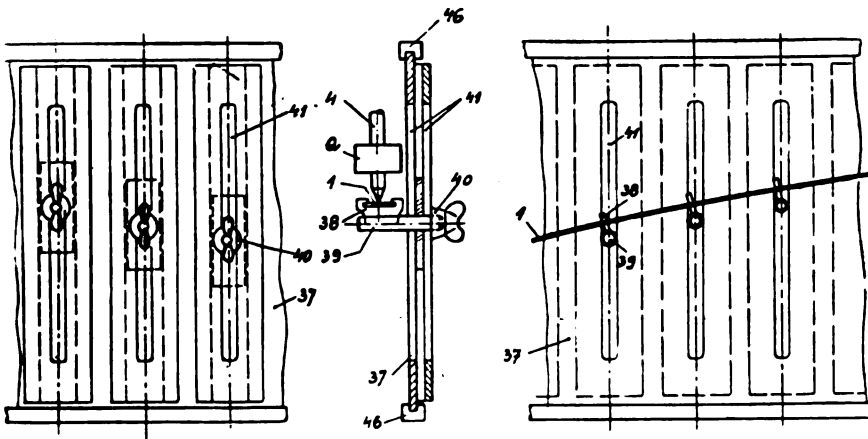


Fig. 61

The steep-tapes *1* are fixed on the special plates *37* one of which is shown in Fig. 61. The tape *1* is clasped by the plate *38* which is born by the axle *39*. On tightening the nut *40* the position of the tape is fixed. The axle *39* is guided by a vertical slot *41* in the plate (slots are not bound to be only vertical; they can be oblique, en chevron, etc.); this axle is revolvable thus enabling the plate *38* to be steadily perpendicular to the tape *1*.

The adjusting of the tapes is carried out in a special frame *42* (Fig. 62). The screws *43* on the upper beam of this frame are constructionally similar to the micrometer-screws. First these screws are adjusted as to suit the ordinates of the curve to be represented by the tape; then the plate *37*

is set into the frame and its tape is allowed to stretch over the points of the screws. Now the nuts 40 are tightened, and so the tape is adjusted and fixed. The plate 37 is then set in the instrument under the corresponding „bridge“. A close-fit positioning of the plate 37 is secured in its traversings (grooved way) 46 in the instrument as well as in the frame 42.

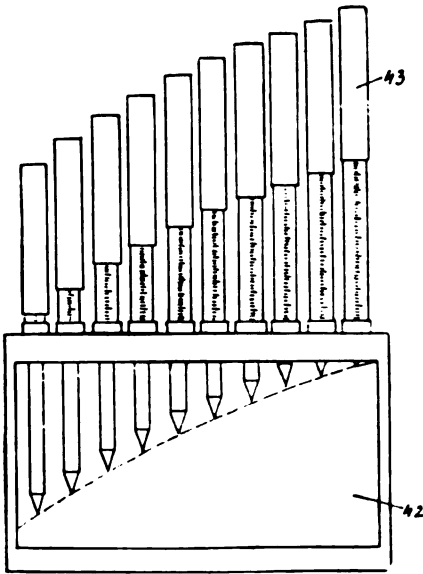


Fig. 62

There are many constructorial ways of fixing the tapes to the plates 37 beside that presented in Fig. 61. One of them, probably very successful, is that presented in Figs. 63 and 64. To the tape 1 is fixed a series of plate supports 67 which have a surface 67 lying on the plate 37. The latter plate is provided with the electromagnets 68 built in it, much the same as in the case of the tables with the machine

tools, so that after actuating the magnets the tape 1 remains fixed to the plate 37.

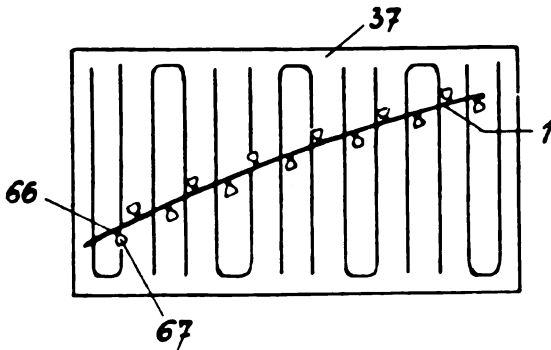


Fig. 63

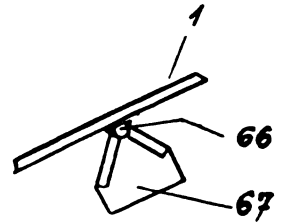


Fig. 64

Similar lines of thought are explored by the solution presented in Fig. 65 where the supports themselves are small electromagnets 69 so that the base plate is of quite a simple construction. In both these cases the supports are fixed to the tapes by hinge-joints so that they can be turned to a certain degree towards the tapes.

Remark should be made that the devices presented by Figs. 63, 64 and 65 might be used not only for function-generation purposes, but also in common draftsman's practice for the drawing of curves; in the first case — Figs. 63 and 64 — electromagnets should be built in the drawing board, whilst in the second case the drawing board should be simply provided with a thin plate over it.

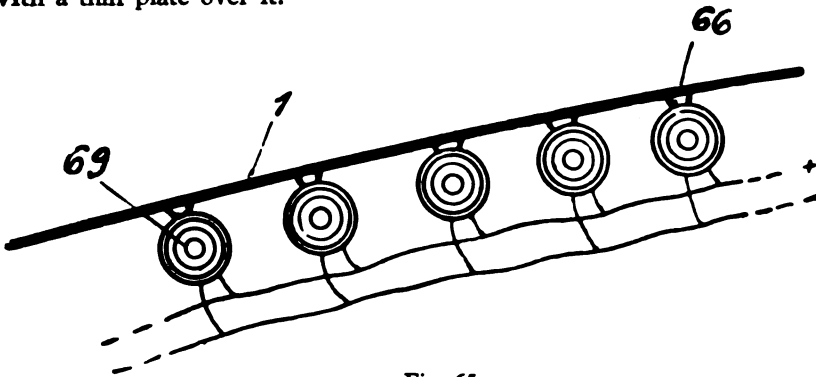


Fig. 65

Drilled plates with tape supports as shown in Fig. 66 can also be used for function-generation purposes. Plate 37 is provided with very many holes. By driving the plugs 32 of the supports into the holes more or less

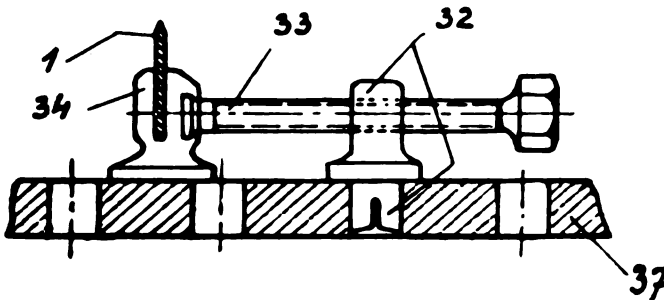


Fig. 66

close to the function a rough adjustment of the tape to the function is made. Fine adjustment is made by means of the screwed spindles 33 which bear the fixatives 34. Taking all into consideration, this type of function generator is quite adequate: It is simple, reliable and largely adjustable to the possible functions.

The vertical plates 37 of all these function generators are moved by the water-line simulator g with the ship analyzers (or by any elements regulating abscissa with general-purpose computers). The needles 4 move verti-

cally thereby (the carriages 3 are fixed and function as mere guidings for needles 4).

The mechanical vertical movement of the needles can be either transmitted further on ³⁰ also mechanically (to the mechanical multiplier-adders), or it can be transformed (by linear potentiometers) into electrical current (or tension) and then treated electrically.

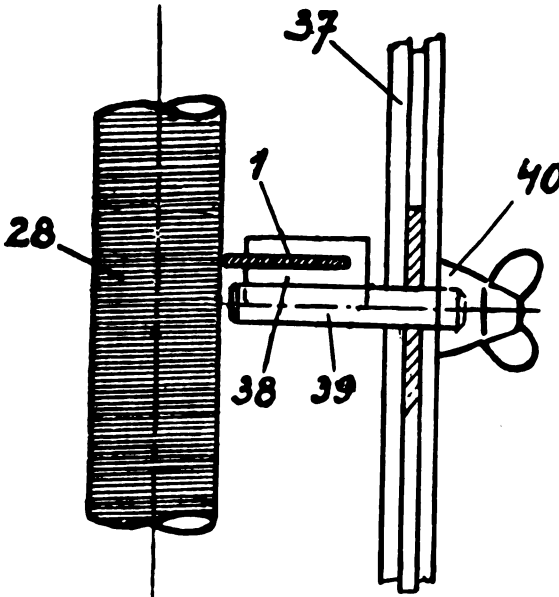


Fig. 67

is left uncovered by the plate 38 now, so that the potentiometer 28 can lean against it freely. Of course, provisions are made to keep the tapes isolated electrically from the other parts now, so that the tape serves the same purpose as the wire 73 with the cemented-wire generator. It is hardly necessary to say that the other tape generators (Figs. 63, 65 and 66) can be also used in this way.

Thus we have obtained a very reliable electrical function generator which can be used for similar purposes as the „cemented-wire“ function generator developed by the Reeves Instrument Corp.

³⁰ As a matter of fact, the device turns out to be a simple cam mechanism. The tape 1 functions as an active rim of the ordinary cam. However, the support of the active rim, i. e., the plate 37, is simply translated rather than rotated. Needle 4 turns out to be a cam-rod.

³¹ The tapes can be made of very many materials (copper, aluminium, etc.) rather than only of steel. For better conductivity the outer rim of the steel tape can be provided with a thin layer of copper, silver, etc.

APPENDIX II

A substantial modification to Gray's original integrator may lead to a new type of optical integrator.

The main features of the original integrator are as follows: a) It is both a function generator and integrator at the same time,³³ b) The integration is performed instantaneously. (In fact, only the function cardboard is

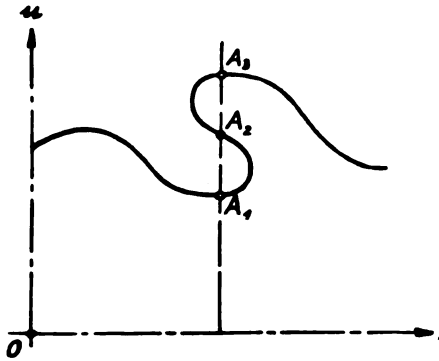


Fig. 67a

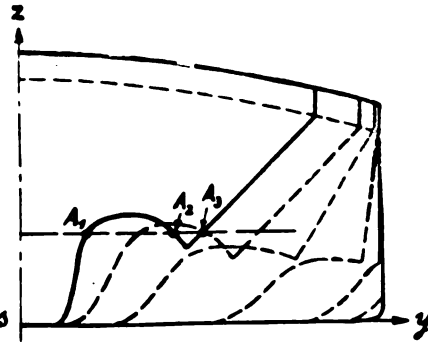


Fig. 67b

the function generator in the true sense of word, but as it is an inherent part of the camera's equipment, the integrator as a whole is a function generator, too).

The case is quite different with other types of integrators. Mechanical integrators, electrical and electronic integrating circuits, etc., are always only integrating devices. Function generators are quite separate devices preceding these integrators, which, on the other hand, are accumulating, hence continuously-integrating elements as against the optical integrator which is an instantaneously-integrating integrator. Both these factors (sepa-

³³ The accuracy of Gray's „integrator“ in both the integration and the function generation may be argued, but, speaking only qualitatively, its capacity of function generating is exceptional. For, whereas there are few function generators which can treat a multi-valued function like that in Fig. 67a, Gray's integrator is just in its own in such cases. And these cases occur in our practice with many inland-waterways ships (especially with tugs) where multi-valued functions are met in Kort-nozzle tunnels (Fig. 67b).

rate function generation and continuous integration) render it feasible for accumulating integrators to integrate even functions which are just being built up, hence which are not known in advance (whose future is unknown from a given moment on).

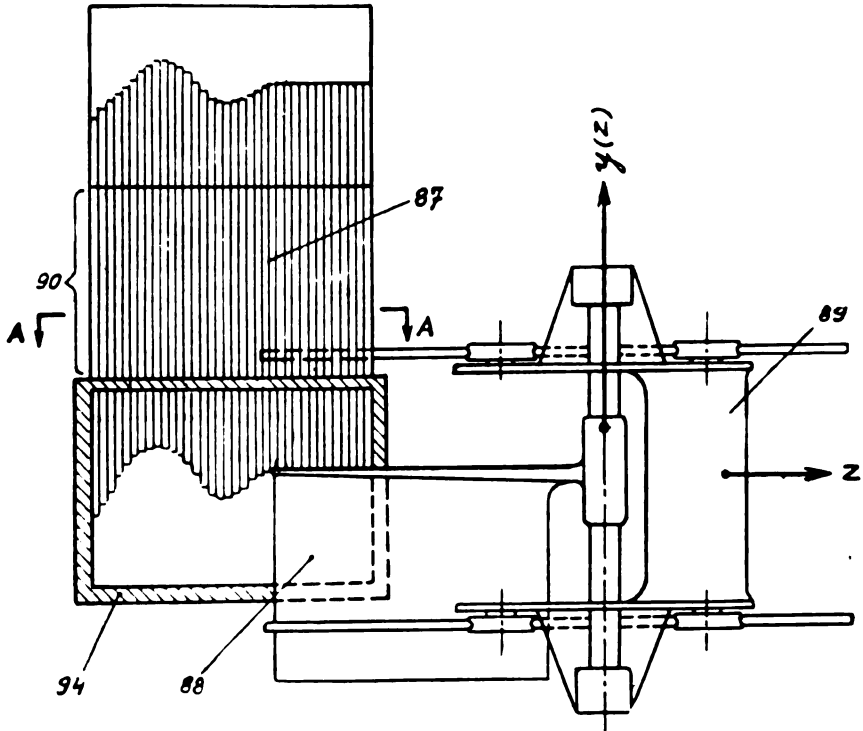


Fig. 68

Such an application of accumulating integrators is made with all sorts of concentrated-integration variants where the integrators receive certain sums (outputs of multiplier-adders) which are just being built up, hence which are not known in advance. In this case Gray's original integrators are not applicable.

A relative continuity of integration can be achieved with optical integrators by means of the screen cardboard sliding along the abscissa of the function cardboard and uncovering more and more its aperture. But the fact that the function cardboard and its aperture are hard and not transformable leads clearly to the conclusion that Gray's (basically instantaneously-doing) integrator, though capable of performing a continuous integration (accumulation), is restricted only for the functions which are known and set (by apertures) in advance.

To render the optical integrator capable of dealing with the functions which are just being formed, it is required to make its function cardboard (rather the aperture of this cardboard) transformable.

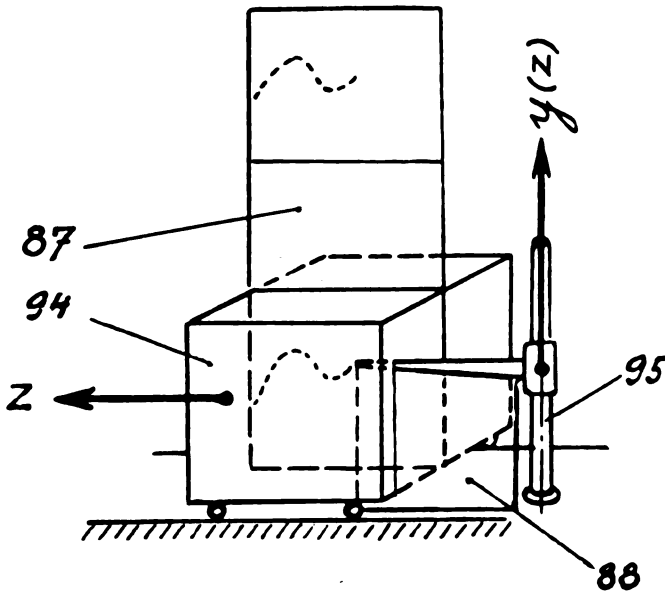


Fig. 69

In Figs. 68 through 71 a feasible variant is shown of such an optical integrator. Instead of the function cardboard lattice screen 87 (Fig. 68) is installed in the camera 94; lattice screen is placed against a vertical screen 88 which is fixed to the carriage 89 outside the camera. Carriage 89 is movable horizontally (abscissa z), and the vertical screen 88 is displaceable against it vertically [ordinate $y(z)$]. In the space 90 of the plane of the lattice screen and above the camera there are mounted the leaf springs 91 behind each of the lattices 92 (Fig. 70). They keep the lattices in the position in which the vertical screen 88 has placed them in its moving along the abscissa and vertically. The springs 91 function as guides to the lattices, too. Vertical screen 88 is allowed to move horizontally in one direction (abscissa steadily increasing). Vertically it is allowed both to raise and sink: As the lower edge of the lattice 92 is entered into the horizontal groove 93 of the vertical screen 88 (Fig. 71) this screen is closely followed in its vertical movement by the lattices still leaning against it.

Instead of the carriage 89 performing displacement z , camera 94 as a whole can do it (see arrows in Fig. 69), so that, carriage being fixed in this

case (now merely pillar 95), the transmission of the y (z) movement from some function generator to the vertical screen 88 can be effectuated more easily.

Hence, this is a new type of general-purpose integrator. It performs an „accumulating“ integration which is not based on time so that the speed

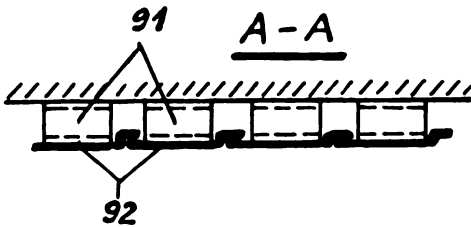


Fig. 70

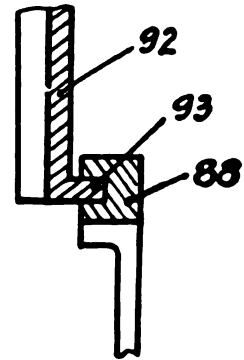


Fig. 71

of integration is not bound to be uniform. In this respect it is similar to mechanical integrators. But the fact that the abscissa can either stand or increase (but not decrease)³³ brings it closer to the electrical integrating circuits.

Hence with a mechanical integrator the abscissa is quite arbitrary as regards both direction and speed. With electrical integrating circuits it is bound to be unidirectional and uniformly increasing. With the new optical integrator it is bound to be unidirectional but not uniformly changing. Hence the new integrator is somewhere midway between the mechanical and electrical (time-based) integrators.

This is the case of the abscissa with the accumulating integrators. With Gray's original integrator, which acts instantaneously, the whole length of abscissa is treated momentarily.

The new optical integrator might be called „accumulating“ optical integrator. It can be evidently used wherever other accumulating integrators are used.

³³ Abscissa not being allowed to decrease with the modified Gray's integrator, this integrator (contrary to the original one) is incapable of treating multi-valued functions (Fig. 67a).

APPENDIX III

The integrator l could be also omitted with the no-time-integration scheme in Fig. 56 if a z -multiplier (presumably a mechanical one) is introduced before the integrator k .

Without that modification, hence with the lay-out as in Fig. 56, the following operation is performed by the integrator k :

$$\int \underbrace{\left[\underbrace{y_i(z) \Delta_i}_{\substack{\text{ordinate} \\ \text{(delivered by } h)}} \right]}_{\substack{\text{abscissa} \\ \text{(delivered by } g)}} dz = \int \mathbf{A}_k dz = D \quad (32)$$

With the same layout the operation performed by the integrator l is as follows:

$$\int \underbrace{z \cdot d}_{\substack{\text{ordinate} \\ \text{(delivered by } g)}} \left\{ \underbrace{\int \left[\underbrace{y_i(z) \Delta_i}_{\substack{\text{abscissa} \\ \text{(delivered by } k)}} \right]}_{\mathbf{A}_k} dz \right\} = \int z \underbrace{\left[\underbrace{y_i(z) \Delta_i}_{\mathbf{A}_k} \right]}_{\mathbf{A}_k} dz = \int z \mathbf{A}_k dz = \mathbf{M}(z) \quad (33)$$

In Fig. 57, with the z -multiplier disengaged, Eq. (32) is valid for the operation of the integrator k . But, with the z -multiplier engaged, the following operation is performed by the integrator k :

$$\int \underbrace{\left\{ \underbrace{[y_i(z) \Delta_i] \cdot z}_{\substack{\text{ordinate} \\ \text{(delivered by } h \text{ and } z\text{-multiplier)}}}}_{\substack{\text{abscissa} \\ \text{(time)}}} \right\}}_{\substack{\text{abscissa} \\ \text{(time)}}} dz = \int \mathbf{A}_k z dz = \mathbf{M}(z) \quad (34)$$

Hence, the end results in Eqs. (33) and (34) are equal, although the starting terms, viz. the data received at corresponding inputs with the integrators l and k in Figs. 56 and 57 respectively are quite different.

The fact that in (32), (33) and (34) the same datum, i. e., the displacement of the water-line simulator g or simply time ($t \equiv z$), has in one case been denoted as dz and another time as z is due to this datum being delivered to the abscissa input in the former case and to the ordinate input of the integrator in the latter case.

APPENDIX IV

A more concrete scheme of a model ship analyzer and a method for the determination of the main elements of the instrument will be presented in this Appendix.

A disposition is given of, say, 25 stations on the longitudinal plan of ship, Fig. 72. This disposition is obtained by the division of the ship's length into 20 intervals whereby two end intervals at each end are further divided into half-intervals.

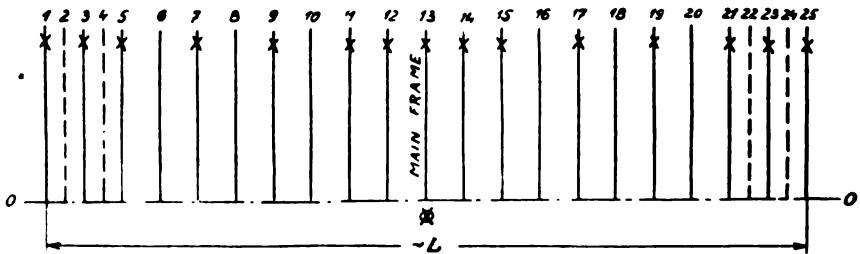


Fig. 72

If we chose an end station as a reference station for the lever-arms the coefficients of the ILA-series (c_i^{II} -coefficients) and those of the IQA-series (c_i^{III} -coefficients) would be too large and the span between the maximum and minimum value of the coefficients would be too broad. Therefore we shall adopt the middle station, i. e., the station No. 13 as a reference station. In this case Table V presents the values c^r ($r = I, II, III$) of the coefficients which, applying Simpson's first rule of integration, are valid for the disposition of stations as shown in Fig. 72.

In this case the largest span of c_i^r -values is that of the IQA-series (c_i^{III} -coefficients), and it is $\kappa = \frac{c_{\max}^{III}}{c_{\min}^{III}} = \frac{196}{4} = 49$.

According to the block diagram as shown in Fig. 57 the basic scheme

TABLE V

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
I-series (c_i^I)	0.5	2	1	2	1.5	4	2	4	2	4	2	4	2	4	2	4	2	4	2	4	1.5	2	1	2	0.5
Lever-arms	-10	-9.5	-9	-8.5	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	8.5	9	9.5	10
ILA-series (c_i^{II})	-5	-19	-9	-17	-12	-28	-12	20	-8	-12	-4	-4	0	4	4	12	8	20	12	28	12	17	9	19	5
IQA-series (c_i^{III})	50	180.5	81	144.5	96	196	72	100	32	36	8	4	0	4	8	36	32	100	72	196	96	144.5	81	180.5	50

of the instrument is presented here by Fig. 73. (Hence the „electronic“ C. I. variant is being considered).

By b_i are designated the function generators which in this case can be any voltage-generating devices: „cemented-wire“ function generators, Fig. 21; tapped potentiometers, Fig. 24; diode-type function generators, etc.

The paths q of the abscissa-commanding elements r with the pick-up assembly p are disposed in the same order and (proportionally) at the same distances as the stations in Fig. 72.

Three multiplier-adders h, h' and h'' are materialized here as resistors h_p . The upper series of resistors (in Fig. 73 the upper series of taps only) belongs, say, to I-series of coefficients c_i^I , the middle one to ILA-series (coefficients c_i^{II}), and the lower one to the IQA-series (coefficients c_i^{III}). These resistors will be called *input resistors*. (Practically, only one series of resistors may exist, but each of the resistors will have 3 taps).

Switch $3I$ includes any of the series of input resistors (or taps) to the amplifier A .

In the case of the run No. 3 of the instrument (see Table III) the current from the bus-bar 173 must first be conducted through a „ z -multiplier“ formed by the potentiometer p_a and resistor p_b and only then to the junction point M . (Wiper 174 of the z -multiplier is

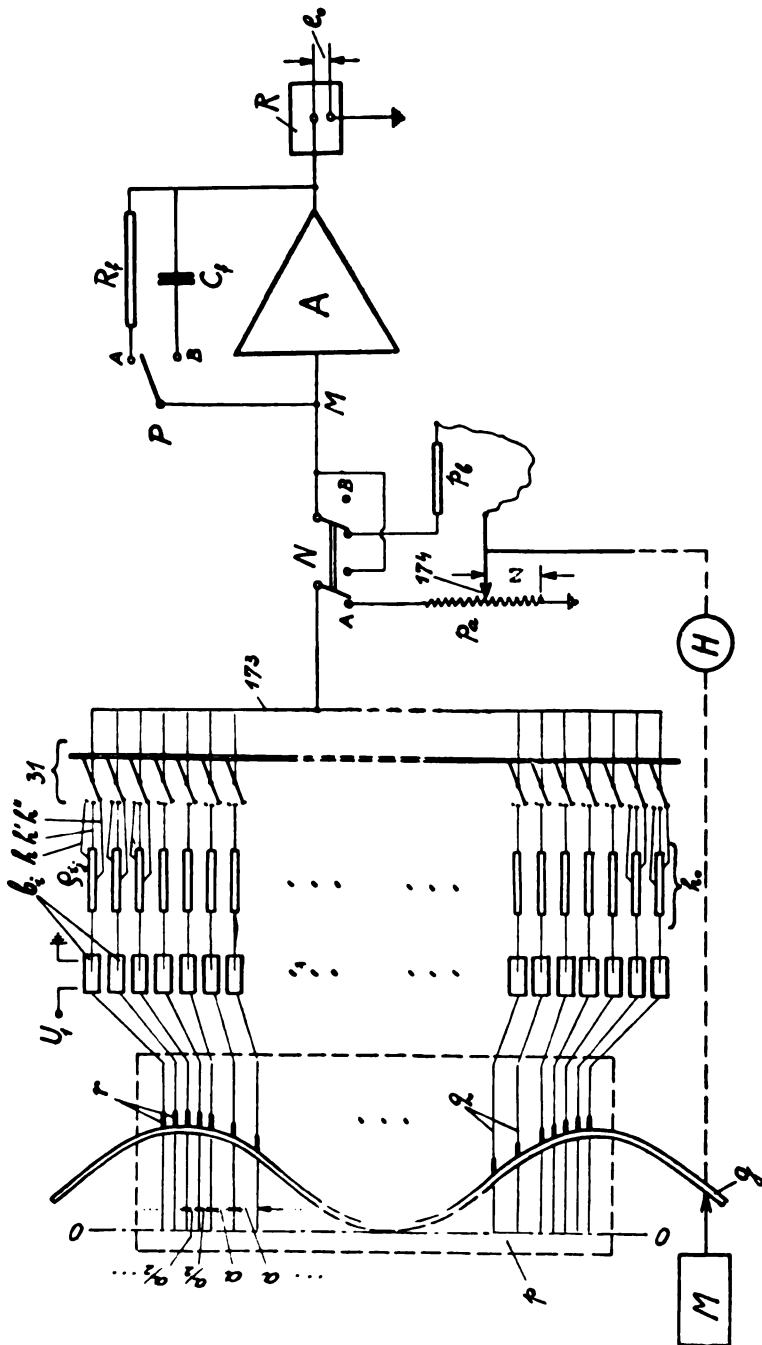


Fig. 73

ganged with the waterline simulator and moves with it uniformly). Once built in the instrument for the run No. 3, z -multiplier will be used in the other runs as well.

Switch P includes in the feedback line either the resistance R_f (summation) or the capacitance C_f (integration). Recorder R registers the output voltage of the amplifier in function of the water-line-simulator displacement.

In the case of the fundamental problem No. 1 the relation (25) is valid. With z -multiplier included as shown in Fig. 73 and with C_f in the feedback line (switches resp. N and P) that relation gives

$$e_0 = -\frac{U_1}{C_f} \int_0^T \left(\frac{a_1}{\rho_1'} + \frac{a_2}{\rho_2'} + \dots + \frac{a_n}{\rho_n'} \right) \cdot \underbrace{z(t)}_{z\text{-multiplier}} \cdot \frac{R_a}{R_b} \cdot dt \quad (35)$$

where:

$a_i = 0 - 1$ = abscissa of a function generator; a_i -s are regulated by abscissa-commanding elements r which are actuated by the water-line simulator g .⁸⁴ In case of the uniform speed of the water-line simulator the relation $a(t) = \frac{t}{T}$ is valid for a_i -values. (a_i = pure number).

ρ_i = resistances of the input resistors ($M\Omega$).

C_f = feedback capacitance (μF).

U_1 = voltage impressed across the function generators (volts).

$z(t) = 0 - 1$ = displacement of the water-line simulator from the starting position; in the case under consideration the integrators based on time are applied so that the water-line simulator's speed must be constant entailing the displacement to be linear; thus, $z(t) = \frac{t}{T}$. [$z(t)$ = pure number].

T = duration of a run (seconds).

R_a, R_b = resistances of the potentiometer p_a and resistor p_b of the z -multiplier ($M\Omega$).

On the basis of (35) we see that the values

$$\frac{1}{\rho_1'}, \frac{1}{\rho_2'}, \dots, \frac{1}{\rho_n'} \quad (36)$$

determine the coefficients c_i^z . (For, the usual value for C_f is $C_f = 1.0 \mu F$).

Hence ρ_i -values must be chosen so that the values $\frac{1}{\rho_1}, \frac{1}{\rho_2}, \dots, \frac{1}{\rho_n}$ are proportional to the coefficients c_i^z , from Table V.

⁸⁴ The values a_i -s should not be confused with the values a_i -s; the values a_i -s are the distances of the paths q of the abscissa-commanding elements r which form the „geometrical component“ of the pick-up assembly p of the instrument.

Minimum value ρ_{\min}^r will correspond to the maximum value c_{\max}^r , whilst the ρ_i^r -values for lower c_i^r -values will be larger than ρ_{\min}^r so that we have

$$\rho_i^r = \frac{c_{\max}^r}{c_i^r} \rho_{\min}^r \quad (37)$$

By determining the values ρ_i^r load errors have to be taken into account: If ρ_i^r -resistances are load resistances for some previous potentiometers, they must be rather high in order to keep load error small.³⁵

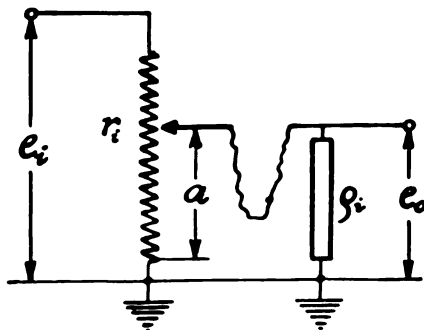


Fig. 74

Hence care should be taken when adopting the lowest value of each of the three series ($r = I, II, III$) of input resistors, while other ρ_i^r -values (which, by (37), are determined as soon as ρ_{\min}^r is known) are not important in this respect.

In the case of the run No. 3 (c_i^I -coefficients valid, see Table III) with $z(t) = \frac{t}{T}$ (clutch H engaged, z -multiplier connected to the water-line simulator g , Fig. 73) and $a_i(t) = \frac{t}{T}$ Eq. (35) gives the following value of the output voltage at the end of a run ($t = 0 - T$ seconds) with $a_i = 1$:

³⁵ Absolute value ϵ of this error (Refs. [8], [9], [13], [18]) is

$$\epsilon = a - \frac{a}{ap + 1 - a^2 p}$$

where:

$$p = \frac{r_i}{\rho_i}, \text{ (see Fig. 74)}$$

r_i = potentiometer resistance (Ω)

ρ_i = load-resistor resistance (Ω)

a = setting (pure number) of the potentiometer wiper ($a = 0$: wiper at the bottom of the potentiometer; $a = 1$: wiper at the top of the potentiometer).

Run No. 3:

$$|e_0| = \frac{U_1 T}{3 C_f c_{\max}^I \rho_{\min}^I} \cdot \frac{R_a}{R_{b_3}} \cdot \sum_{i=1}^{i=n} c_i^I \tag{38}$$

When deriving Eq. (38) the formula (37) has also been used.

In the case of the run No. 2 (c_i^{II} coefficients valid, see Table III) with $z(t) = \text{Const.} = K_2$ (clutch H disengaged, z -multiplier included but set to $K_2 = \text{Const.}, 0 < K_2 < 1$) and $a_i(t) = \frac{t}{T}$ Eq. (35) gives the following value of the output voltage at the end of one run ($a_i = 1, t = T$):

Run No. 2:

$$|e_0| = \frac{U_1 T K_2}{2 C_f c_{\max}^{II} \rho_{\min}^{II}} \cdot \frac{R_a}{R_{b_2}} \cdot \sum_{i=1}^{i=n} c_i^{II} \tag{39}$$

In this case, since $\sum c_i^{II} = 0$ (due to the symmetrical two-sign lever-arms, see Table V), Eq. (39) yields $e_0 = 0$ if all a_i -values are equal.³⁶ If a_i -values for one half of the stations are $a_i = 1$ and for the other half are $a_i = 0$, then e_0 is maximum.

In the case of the run No. 1 (c_i^I coefficients valid, see Table III) with $z(t) = \text{Const.} = K_1$ (clutch H disengaged, z -multiplier set to $K_1, 0 < K_1 < 1$ and $a_i = \frac{t}{T}$, Eq. (35) yields the following values for the output voltage at the end of a run ($a_i = 1, t = T$):

Run No. 1:

$$|e_0| = \frac{U_1 T K_1}{2 C_f c_{\max}^I \rho_{\min}^I} \cdot \frac{R_a}{R_{b_1}} \cdot \sum_{i=1}^{i=n} c_i^I \tag{40}$$

In the case of the fundamental problem No. 2 the relation (23) is valid ($Z_f = R_f, Z_i = \rho_i$). With z -multiplier included (Fig. 73) and with R_f in the feedback line (switch P) that relation gives

$$e_0 = -U_1 R_f \sum_{i=0}^{i=n} \left(\frac{a_1}{\rho_1} + \frac{a_2}{\rho_2} + \dots + \frac{a_n}{\rho_n} \right) \cdot \underbrace{z(t)}_{z\text{-multiplier}} \cdot \frac{R_a}{R_b} \tag{41}$$

where

$R_f =$ feedback resistance ($M\Omega$).

³⁶ Two-sign coefficients c_i^{II} are established by impressing the voltage $+ U_1$ across one half of the function generators and the voltage $- U_1$ across the other half.

In this case summation is performed by the amplifier- A circuit rather than integration. Therefore it is not necessary for a run to begin from $a_i = 0$ for all the stations.

In the case of the fundamental problem No. 2 z -multiplier is not ganged with the water-line simulator g (clutch H disengaged). It is set to a constant K_s ($s =$ run index), i. e., $z(t) = K_s$, ($0 < K_s < 1$).

In the case of the runs Nos. 4, 5 and 6 coefficients c_i^I , c_i^{II} and c_i^{III} are valid respectively so that Eq. (41) gives (for $a_i = 1$):

$$\text{Run No. 4: } |e_0| = \frac{U_1 R_f K_s}{c_{\max}^I \rho_{\min}^I} \cdot \frac{R_a}{R_{b_s}} \cdot \sum c_i^I \quad (42)$$

$$\text{Run No. 5: } |e_0| = \frac{U_1 R_f K_s}{c_{\max}^{II} \rho_{\min}^{II}} \cdot \frac{R_a}{R_{b_s}} \cdot \sum c_i^{II} \quad (43)$$

$$\text{Run No. 6: } |e_0| = \frac{U_1 R_f K_s}{c_{\max}^{III} \rho_{\min}^{III}} \cdot \frac{R_a}{R_{b_s}} \cdot \sum c_i^{III} \quad (44)$$

Since $\sum c_i^{II} = 0$ for a_i -values being equal, the same remark is valid for Eq. (43) as for Eq. (39).²⁷

Usual values for U_1 , C_f and R_f are: $U_1 = \pm 100$ volts, $C_f = 1.0 \mu\text{F}$ and $R_f = 1.0 \text{M}\Omega$. Duration T (seconds) of a run amounts to a couple of minutes (1 to 4 minutes). It can be adopted arbitrarily. The values of the coefficients c_i^r are determined by Table V, i. e., by the disposition of the stations (so the values c_{\max}^r and $\sum c_i^r$ are known, too). Output voltage e_0 is restricted by the recorder; the standard allowable voltage for the recorder is $E_{0\max} = 100$ volts, thus $|e_0|_{\max} = 100$ volts.

Hence all the values are known in the formulas (38), (39), (40), (42), (43) and (44) except the values ρ_{\min}^r , R_a , R_{b_s} (load error considerations require $R_{b_s} > R_a$) and K_s . Therefore, these values have to be adopted so that they satisfy the formulas (38), (39), (40), (42), (43) and (44) on the one hand, and so that the other conditions relating to them (load error considerations with ρ_i^r values, $0 < K_s < 1$, $R_{b_s} > R_a$, etc.) are fulfilled on the other hand as well. Thereby the value ρ_{\min}^I must satisfy the Eqs. (38), (40) and (42)

²⁷ In the case of the runs Nos. 1, 3, 4 and 6 it was assumed for a_i -values to be $a_i = 1$. This corresponds to the end of a run when $e_0 = e_{0\max}$. To be sure that e_0 will not be higher than $E_{0\max}$ ($E_{0\max} =$ maximum allowable voltage to be fed to the recorder), $e_{0\max}$ must be laid down as a basis for the calculation with the runs Nos. 2 and 5, too. Hence with these runs the assumption must be made that one half of a_i -values are $a_i = 1$ while the other half are $a_i = 0$.

at the same time, ρ_{\min}^{II} the Equations (39) and (43), and ρ_{\min}^{III} only the Equation (44). K_i values (settings of the wiper of the z -multiplier) are in general different for each run and so are the values R_{b_i} with $R_a = \text{Const.}$ (R_{b_i} is materialised as a resistor with several taps).

By trial-and-error method the values ρ_{\min}^r , R_a , R_{b_i} and K_i , satisfying all the conditions mentioned can be found before long. The values ρ_{\min}^r once determined, so are also all the ρ_i^r values [Eq. (37)].

Thus all the main elements of a d-c model ship analyzer can be determined. There are, indeed, some side calculations to be made, but we shall not enter into discussing them here.

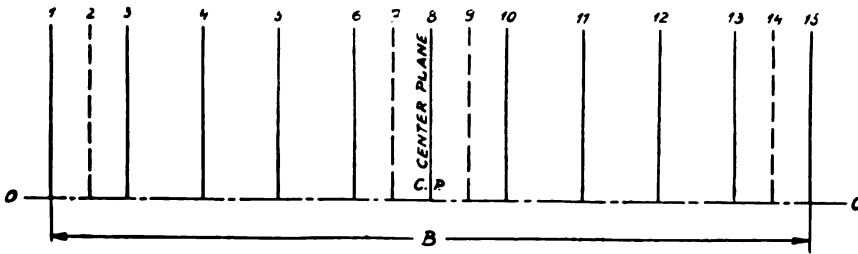


Fig. 75

As the pick-up assembly p of the instrument has to be used when working on both longitudinal and transversal plan, in the latter case only the paths (and corresponding function generators) marked by x in Fig. 72 will be used. This corresponds to the division of the ship's breadth into 10 intervals whereby two end intervals and two middle ones are divided into half-intervals (Fig. 75). This is done on account of the specific form (singular point in the middle) of the curves (Fig. 10 *b*) which are to be treated by the instrument in this case.

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