Vibration in ships.

By **N. W. Akimoff**, Esq., President & Treasurer of Vibration Specialty Co., Philadelphia, U. S. A.

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It has been of only comparatively recent date that any practical method has been evolved for the analysis and elimination of vibrations in ships, building, rotating bodies, etc. Vibrations in vessels, since the day that propelling machinery was first installed, have been a very serious problem. In all vessels they cause unwarranted deterioration. In pleasure craft and passenger vessels, it is not an uncommon occurrence for a vessel to have to alter her speed to other than that for which it was designed, because of excessive vibrations in some particular part, usually where passengers mess or lounge, and again it may be on the bridge where the nautical instruments are, making them difficult to read, or throwing them out of adjustment.

In naval vessels of all nations, vibrations produce a problem more serious than in other classes of vessels, because there are times when vessels, to fight properly, must operate at certain set speeds. These speeds may be such that the vessel vibrates excessively, thereby greatly reducing her fighting efficiency. All the larger naval vessels have a great number of accurate instruments located in the fighting tops and on the platforms on the masts. These positions naturally have great amplitude of vibration, when vibration exists, in the vessel, thereby making the reading of the instruments inaccurate. Long range firing is especially effected by these conditions. There are records upon records where the range finder in the fighting top could not be used because of excessive vibration. Practically every country having another type of war vessel, the submarine, great difficulty has been experienced in running at designed speed because of vibrations. Speed reductions of as high as 25% have been required before some vessels of this type would operate satisfactorily.

As regards the effects of vibrations on the machinery of vessels, there are a great many records of cases of broken shafting, of throwing propeller blades, bearings destroyed, destruction of struts and rudders, throwing of binding wires and commutator bars, turbine blading stripped, broken steam lines, broken turbine casings, etc. It was the numerous problems of this nature that brought N. W. Akimoff, the founder of the Vibration Specialty Co. into the field of vibrations.

Mr. Akimoff began first by evolving means for analyzing unbalanced forces and eliminating vibrations in rotating bodies. For this work he developed a balancing machine. Following this development came that which had to do with the vibrations produced by torsional effects. Various instruments, such as the vibroscope, and torsiograph have been developed for assistance in the study of the various vibration problems.

Vibrations in vessels are produced in serveral different ways:

1. Those vibrations caused by external forces, that is by the wind and sea.
2. Vibrations produced by uniform winding and unwinding of the shaft, otherwise known as torsional.
3. Vibrations caused by improper design, such as the improper location of propeller, irregularity in pitch of propeller, unequalized work in cylinders, etc.
4. Vibrations caused by shifting inertial forces, such as is effected in a four or eight cylinder engine, where the resultant center of gravity of the reciprocating parts makes a prescribed shift for each revolution of the engine.
5. Plain unbalance.

For the practical elimination of vibration in vessels, we first proceed to overcome the effect of those vibrations produced by the forces as designated above under headings 2, 3, and 4.

The detail plans of a ship's hull are first developed and the characteristics pertaining to vibration of all parts of the hull are accurately ascertained. This includes data for the equitorial moment of inertia diagram, and the data for the loading diagram. Following the establishment of the hull characteristics, the machinery is developed into elastic systems with a finite number of degrees of freedom. The data are analyzed and characteristics of the location of the various parts of the machinery are obtained. The various pieces of machinery referred to above are such combinations as the assembly of the turbine, reduction gear, shafting, propeller, and also the assembly of the various auxiliary units. In this analysis there comes up frequently the fact that torsional vibrations exist in the shafting of the machinery. This calls for a change of design, so that there will be no torsional vibrations within the range of the natural period of hull vibrations. The above analysis also includes the ascertaining of the vibrations produced by those machines which have shifting inertial forces that in no way can be eliminated by balance. This machinery includes such auxiliaries as are driven by engines having single throw-cranks, four cylinder, four cycle, internal combustion engines and reciprocating pumps. The last, as a rule, produce effects which are very minor in their effect on a vessel, when compared to the effects of the main propelling machinery and large generating units sometimes found in a ship.

After the characteristics of the hull and machinery are ascertained, the location of all machinery can then be definitely laid down and the construction work of the vessel begins. I might add here that this position of location of machinery is in a great measure essential in order that the vibrations produced by the machines will not synchronize with the periods of the loaded hull.

Furthermore, it is absolutely essential that no changes in the hull, or machinery, in any respect be made after the final analysis of the data. The change of characteristics in any particular element in a combination will change the characteristic of the whole combination, thereby making any previous calculations useless.

The vibrations coming under the first heading are not regular in occurrence and are practically impossible to correct.

Those vibrations coming under the fifth heading—in other words, the ones produced by static and dynamic unbalance in the rotating parts are eliminated by means of balancing those parts. At this point I will state just what is meant by static and dynamic unbalance.

Static unbalance means that the center of gravity of the body does not lie exactly on the axis of rotation. Dynamic unbalance means that there is a centrifugal couple in a body that is two heavy points on opposite sides of the shaft, but not in the same transverse plane. A two-throw crankshaft would be a good example of this condition, except that here the centrifugal couple can be seen right from the drawing and balancing machine would be unnecessary.

For the static and dynamic unbalance of rotating bodies, Mr. Akimoff has devised two types of machines. The first type is known as the Combination Static and Dynamic Balancing Machine and balances first statically and then dynamically. The second type gives data which determine both static and dynamic unbalance in one operation.

Figure No. 1 gives an idea of the layout of the first type of machine. A frame F supports the bearings B and C, which carry the body. The frame has a swinging period of its own. The bearing C may either be locked, so that it acts exactly like the rigid bearing B, or else it may be allowed to float in a vertical plane, bringing into play certain resistances (springs) opposing its deflection from the neutral (vertical) position. The correcting centrifugal force is indicated by K.

Such a system is known in dynamics as system with two degrees of freedom, in general being capable of two kinds of motion: swinging of the frame, the bearing C being maintained rigid; and swinging of the bearing C, the frame F being maintained rigid by such means as brackets S; while the most general motion consists of a combination of these two motions.

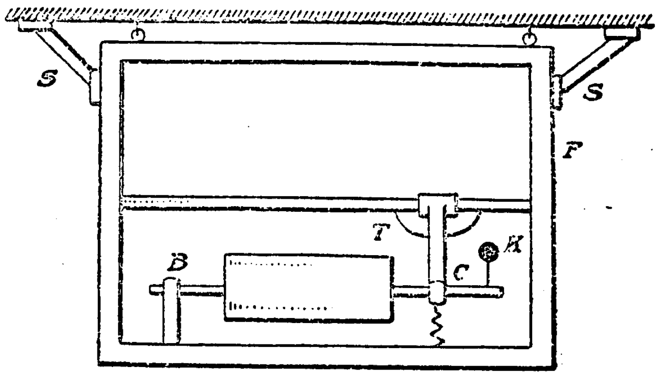

Fig. 1.

The operation of such a combination machine is very clear. In order to secure static balance we lock the bearing C and unlock the frame supports S. Then, by properly adjusting the magnitude and direction of K we can reduce to zero the bodily oscillations of the frame F, thus establishing the exact value and sign of static unbalance in ounce-inch units. As soon as this has been corrected, we lock the frame F and unlock the bearing C, when the same centrifugal force K, created by a suitable adjustment of the clamp, as explained above, can be made to correct the body for dynamic unbalance.

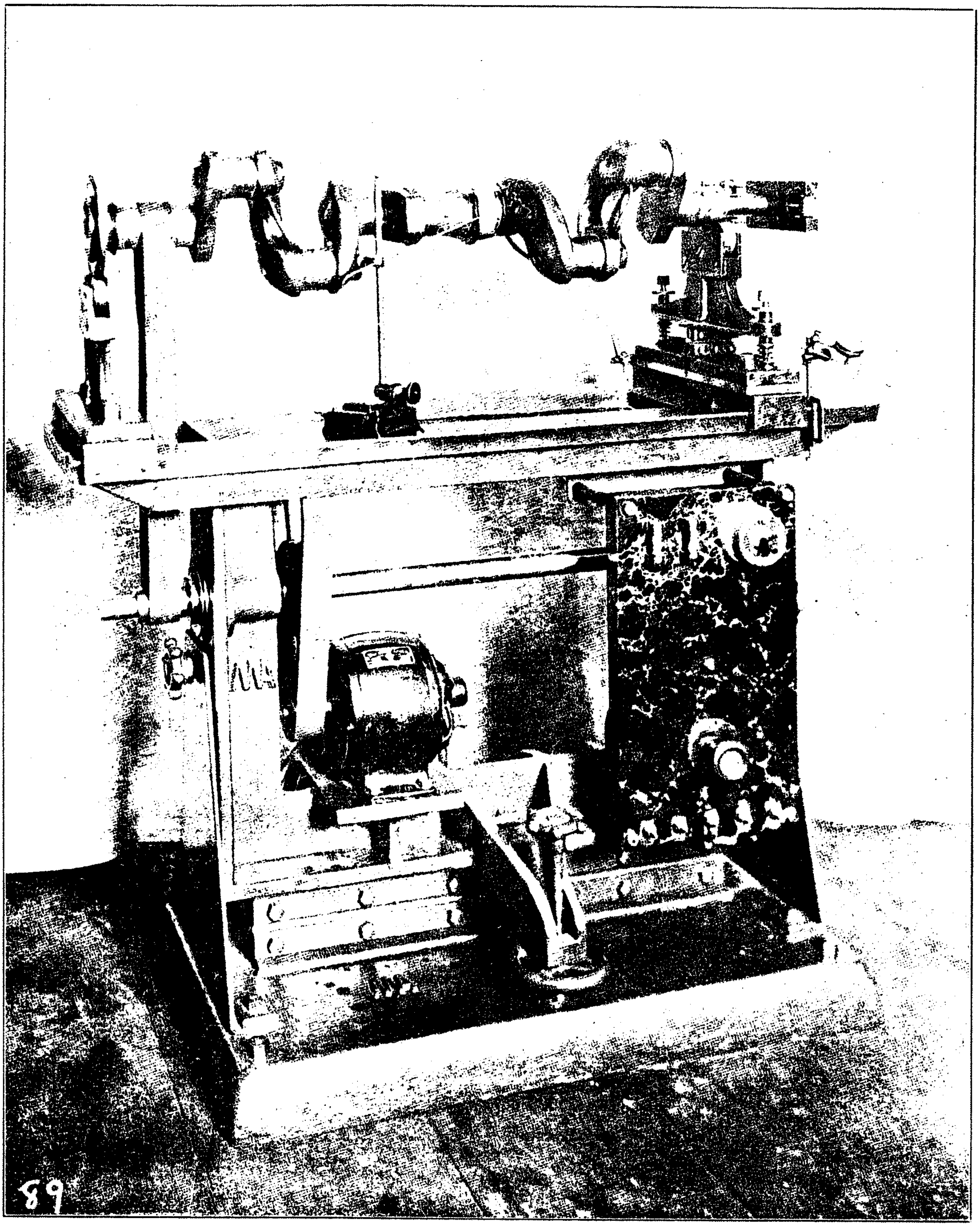

Fig. 2.

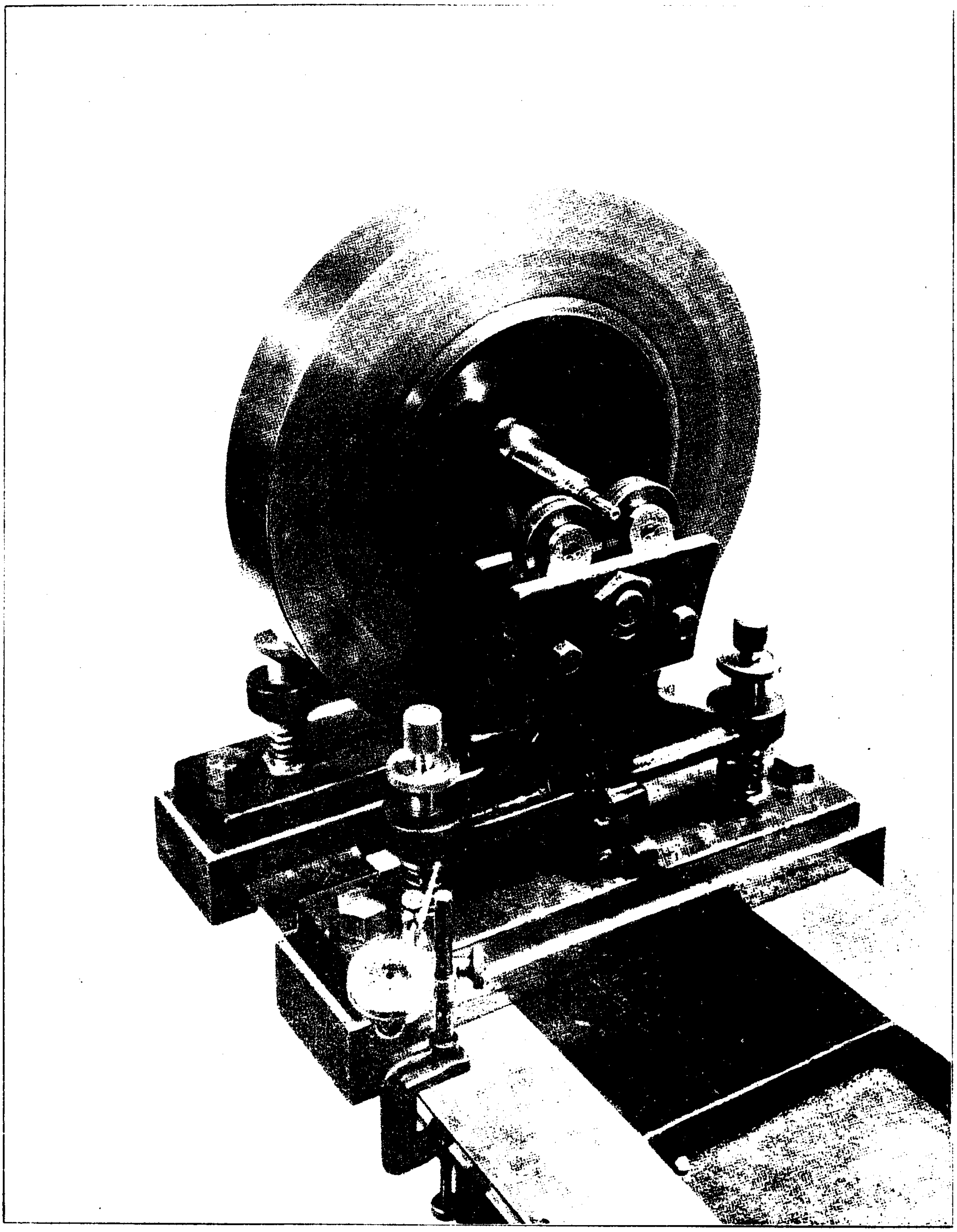

Fig. 3.

The advantage of basing the results on centrifugal force instead of on a centrifugal couple is manifest, the former being a fundamental, and the latter a derived unit, so that the former is capable of much greater accuracy in adjustment and of more direct application than the latter.

Figure 2 shows the first type of machine in its final stage of development.

Figure 3 shows the dynamic supports of this machine with a gyroscopic compass rotor on them. In this figure it will be noted that the dial is absolutely steady, while the gyro wheel is being run on the machine. If unbalance existed, this dial would vibrate to a greater or lesser degree, depending on greater or lesser amount of unbalance in the wheel. All static balancing is done by rotation, oscillation of the indicator dial indicates that vibrations are present, and that unbalance exists. In such work as the above mentioned gyro wheel, a static balance has to be unusually accurate in its accomplishment, in order that the dynamic balance may be absolutely accurate. This stands, of course, for all work we balance on our machines, that is, the body must be in perfect static balance before a perfect dynamic balance can be obtained. These gyroscopic compass wheels, as you all know, run at a very high rate of speed and the slightest unbalance in them has a very pronounced effect.

The clamp shown on the right hand of the crankshaft on the balancing machine, in figure 2, is used to introduce the centrifugal force to counteract the centrifugal force of whatever the unbalance may be. The dynamic support, which supports the right of the crankshaft in this figure, is first locked and the static support, or spring which is shown on the base of the machine, is released so that the table will vibrate in a horizontal plane at right angles to the axis of rotation of the body being balanced. The body is then run up through its critical speed and the clamp attached to introduce the counter centrifugal force, the correctors applied in the proper plane to eliminate the static unbalance. The base is then secured and the dynamic bearing on the right released, and using the same clamp, data are obtained which give a reading in ounces times inches times inches, which is the value of the dynamic couple. From this information, a dynamic couple opposite in sign is applied, which brings one of the principal axes of the momental ellipsoid of the body into coincidence with axis of rotation.

Figure 4 shows the second type of balancing machine, which is made primarily for handling heavy weights. It is very light and very sensitive, the principal parts being two vibrating supports and the thrust. As in the first type, this machine gives data which allow for a very accurate correction for both static and dynamic unbalance. Using the equipment mentioned in this paper, especially in the balancing machinery on propellers, reduction gear and turbine rotors, has made an astounding difference in ship operation. Since we have accurate means of determining (in ounce inches—static, and ounces times inches times inches—dynamic) the unbalanced forces that exist in bodies, it has been a very simple matter to calculate their effect on bearings and ship structures.

In this day of high velocity machinery, the strains put on various parts by these unbalanced forces are tremendous and the danger to personnel is not to be taken lightly.

In regard to balancing, there have been several erroneous ideas presented by various people, who apparently do not understand the fundamentals, or else have not given the matter sufficient thought.

We have had cases where an engineer of a large plant stated that he balanced heavy bodies accurately on knife edges and carefully applied his corrections with reference to the center of gravity, and that in so doing, the dynamic couple, which if it existed, was so small that practically no vibrations were produced. This is incorrect—first, because it is absolutely impossible to balance accurately on knife edges, and secondly, because we have found bodies in perfect static balance which had such a pronounced dynamic couple that it was absolutely impossible to generate sufficient power to operate them through the critical speed.

Again, we have had a case of a balancing machine manufacturer who claimed that by the application of one weight he could make correction for both the static unbalance and the dynamic couple. This is in error because the correction of the above named combination requires at least three weights, one for the static and a pair of weights located in the same axial plane, 180° apart on the opposite ends of the body to be balanced, to correct for the dynamic couple. Of course, a combination of two weights, one at each end, in the resultant plane, which is a resultant of the static and dynamic for that end, may be applied instead of applying three weights, or four weights as the case may be, four weights being

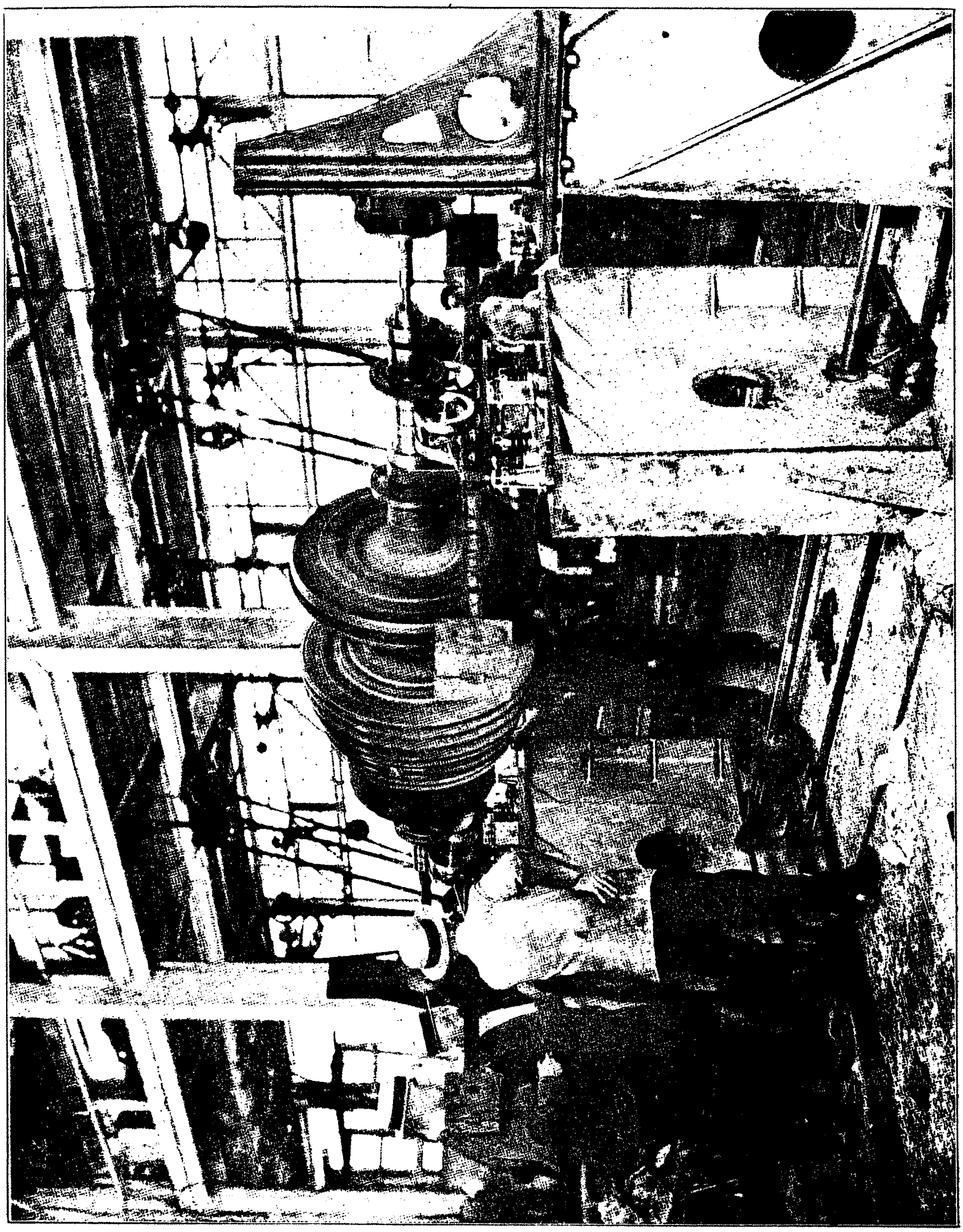

Fig. 4.

used when the static is divided between the two ends of the rotor.

It is quite evident that the time is here when there must be close cooperation between the naval architect and the marine engine designer, in order that some such system as the Vibration Specialty Company has evolved will come into vogue in the building of every vessel, so that all destructive and otherwise undesirable vibrations in ships may be eliminated.

Discussion.

Engineer-Commander Nobutake Enya, I. J. N.—It is a great pleasure to us to have a valuable paper prepared for our jubilee meetings by Mr. N. W. Akimoff on vibration in ships and his balancing machine. The balancing is no doubt one of the most important problems in modern mechanical engineering, because vibration is one of the causes of troubles with high speed machineries. We have had a quite number of balancing methods but none of them is scientific. I am very glad that through Mr. Akimoff's energetic investigation, this important problem has finally been solved; the new method invented by him is a scientific one which gives satisfactory results, saving much time and expense.

With regard to vibration we have to keep in mind that the non-uniformity of wake behind a ship is a main factor inducing vibration in the ship. The speed of wake is not same at every point of current in which screw propeller works, and the fluctuation of the wake gives the different slip and causes the vibration of the propelling machinery. Main engines of a war vessel must be very well balanced, because in her, weight and space do not allow to make them superfluously strong. The engineers of Japanese Navy have done their utmost by several methods to get the best balance of machines and of their parts, such as turbine rotors, reduction gears, screw propellers, rotary pumps, Diesel engines, gasoline motors, etc. I am specially interested with this branch of engineering, and after a thorough investigation on several kinds of balancing machines, I came to the conclusion that the Akimoff machine is best of all.

When No. 3 machine was supplied to Japanese Navy in 1921, I was in Philadelphia, with commander K. Kajimoto, I. J. N. and our assistant engineer T. Namikawa, and we had the pleasure of having an interview with Mr. Akimoff and of hearing the explanation on his machine personally from him. I am very pleased to tell the writer of this paper that the main steam turbine of the Oil-Tanker "Kamoi" of Japanese Navy, which develops 8,000 S. H. P. and is coupled to the main generator, was balanced by Akimoff's machine at the Schenectady Factory of General Electric Company, and was found to work satisfactory.

Mr. Namikawa who has studied in detail for several days how to use the machine at Mr. Akimoff's Philadelphia factory is now experimenting it at a factory of our Navy Yard, and I expect that I may give the report of the experiment to the writer before long.

Mr. N. W. Akimoff:—In connection with the comments by Engineer-Commander Nobutake Enya, I. J. N., we agree that there are certain periodic uniform changes in a vessel's wake which produce vibrations. They are of such a nature that they may be analyzed and their period accurately ascertained because the vibrations thus produced are caused by forces controlled by the vessel. The propeller is the most vital factor in this particular case and its type, speed, and location must be carefully studied. The study of these vibrations is a part of the whole study referred to in my paper.

Since we are discussing the subject of Vibrations, the thought occurred to me to add a few records, which might be found of interest.

Diagram A illustrates the vibration of which the frequency was exactly in accordance with the number of revolutions. This illustrates one of two things: either the propeller is out of balance, or the engine is located upon the boat in such a place that it is sensitive to the reciprocating action of the three-cylinder mechanism.

Diagram B illustrates something entirely different. In the first place, the frequency of the wave line is three times the number of revolutions, clearly indicating the defective action of the propeller. Furthermore, it will be observed that every third wave is more prominent than the adjoining ones. Upon investigation it was found that the cylinders of this triple-expansion engine were not adjusted properly, so that the H. P. cylinder was doing twice the work of each I. P. and L. P. cylinder.

It frequently happens that a propeller which acts very well, and gives no trouble of any sort, all of a sudden begins to cause vibrations and considerable loss of efficiency. If this occurs, investigation might be made as to whether some obstruction has been struck by one of the propeller blades, with the resulting injury to same.

As regards balancing proper, I might say that at the present time this has become a true shop method, and I sincerely hope that it no longer presents any mysteries to either the builder or the user of high speed apparatus.

Diagram. A.

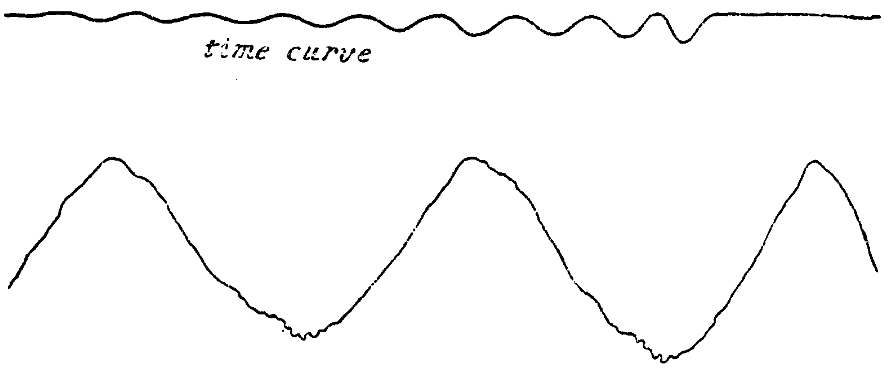

Diagram. B.