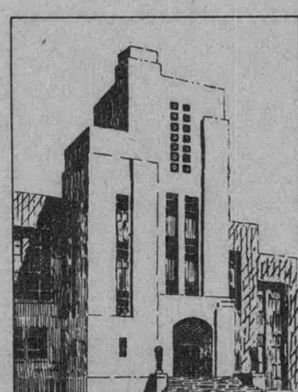
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

CONSTRUCTION AND OPERATION OF THE LOSENHAUSEN 44,000-POUND VIBRATION GENERATOR

BY E. O. BERDAHL



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REPORT 554

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PERSONNEL

This machine was purchased at the suggestion of Capt. W.P. Roop, USN, while a member of the staff of the U.S. Experimental Model Basin. Whenever it has been used, it has been operated under the direction of R.T. McGoldrick, of the Structural Mechanics Division.

This report was written by E.O. Berdahl. The numerical data were checked by R.B. Allnutt, and the electrical data were checked by S.E. Dawson, of the Engineering and Design Division.

CONSTRUCTION AND OPERATION OF THE LOSENHAUSEN 44,000-POUND* VIBRATION GENERATOR

ABSTRACT

The large Losenhausen vibration generator of the David Taylor Model Basin, which is capable of producing large vertical sinusoidal forces at low frequencies, is described. It is used to investigate the dynamic characteristics of large structures such as bridges and ships.

The design and operation of the machine are described in detail.

The machine weighs 49,000 pounds and the control apparatus approximately 500 pounds; both have suitable lugs for handling by a crane. The machine can develop a vertical sinusoidal force with a maximum single amplitude of 44,000 pounds at speeds from 105 to 480 RPM, and will generate a comparable maximum force of 11,700 pounds in the same direction at its lowest running speed of 54 RPM. It is operated on d-c power, and the total rated power consumption of the two driving motors is 30 kilowatts.

INTRODUCTION

Since the late 1920's German scientists and engineers have been investigating the elastic properties of structures by determining their vibration characteristics (1)(2).** Their system consisted in mounting a vibration generator on a structure, running it to set the structure in resonant vibration, and comparing the stiffness thus found with the calculated stiffness. If the natural frequency and corresponding stiffness were found to be lower than the estimated satisfactory values, it was assumed that either the joints were not sufficiently rigid or there was a defect somewhere in the design or construction of the structure.

The possibilities of investigating the elastic characteristics of ship structures and models greatly appealed to the then Bureau of Construction and Repair and to the U.S. Experimental Model Basin. In 1929 arrangements were made to purchase from the Losenhausen Werke in Düsseldorf, Germany, a large vibration generator weighing about 50,000 pounds, which would produce a maximum exciting force of 44,000 pounds, and a small vibration machine weighting 140 pounds (3) and capable of producing a maximum exciting force of 440 pounds.†

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* The rating of a vibration generator is expressed customarily in terms of the maximum single amplitude of the periodic force which it can develop for continuous operation. It so happens that the nominal force rating and the weight of this machine are of about the same magnitude.

** Numbers in parentheses indicate references on page 27 of this report.

† The builders, since they were working in the metric system, designed these machines to produce a maximum exciting force of 20,000 and 200 kilograms respectively. Hence, the rated forces appear as odd values in the English system.

The small machine has been used extensively since it was delivered in 1931. The large machine, with which this report deals, has been employed on several occasions.*

The large vibration generator will excite large structures in low natural frequencies, 54 to 480 RPM, whereas the small machine has a large speed range, 300 to 3000 RPM, but has a relatively small exciting force. The schematic arrangement of the large vibration generator is shown in Figure 1.

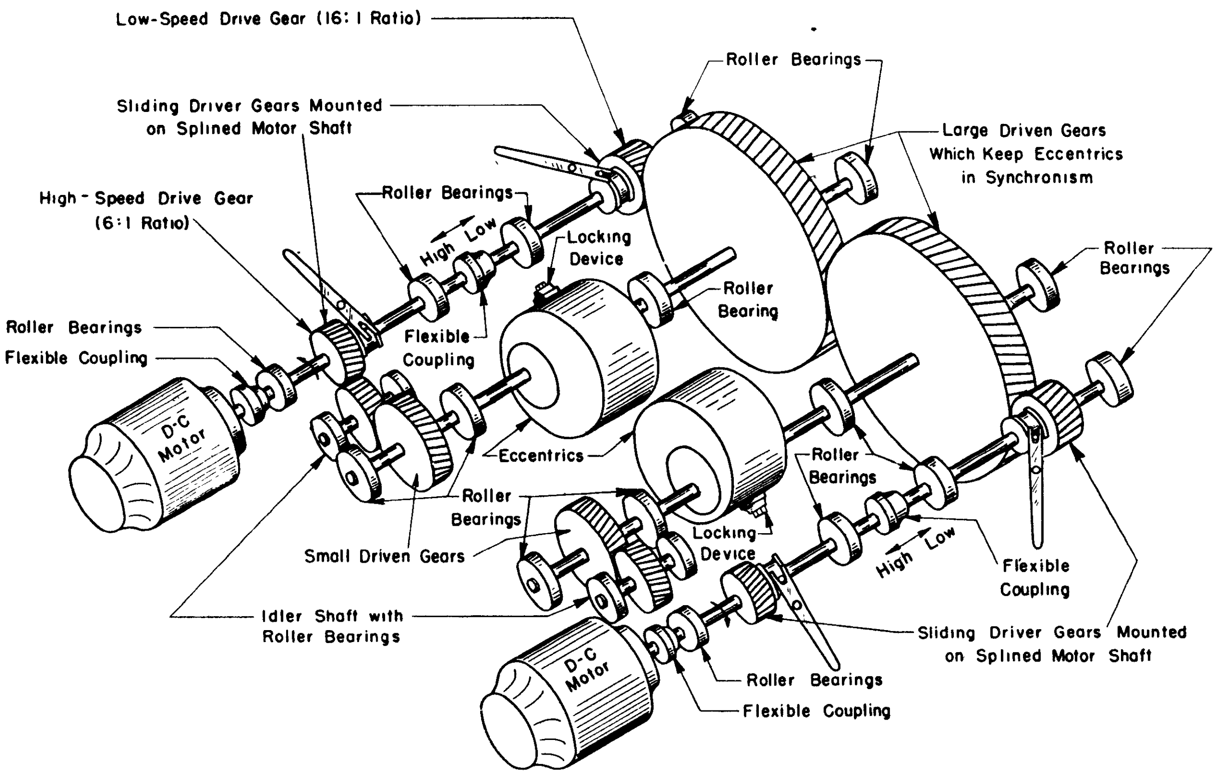

Figure 1 - Schematic Arrangement of Eccentrics and Drive in the Losenhausen 44,000-Pound Vibration Generator

Each main shaft carries an eccentric weight assembly and is supported by four roller bearings. Each main shaft carries a high-speed driven gear and a low-speed driven gear; the low-speed driven gears serve to keep the shafts in synchronism. Each set of high-speed transmission gears includes an idler gear supported by two roller bearings. The driver gears can slide along the splined portion of the motor shafts, permitting the choice of two transmission speed ratios. Two flexible couplings are inserted in each motor shaft, one between the motor and the high-speed gear, and one between the high-speed gear and the low-speed gear. Neither the rods connecting the gear-shift levers nor the locking levers are shown in the sketch; for these see Figure 16. All gears indicated above are of the helical type. The driving motors rotate outboard as indicated. The arrow designated as "high" points toward the gear train which is in mesh when the speed reduction is 6:1. The arrangement is here shown in "low" gear and the speed reduction is 16:1.

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* To supplement the two German machines purchased in 1931, the David Taylor Model Basin designed and built a medium vibration generator (4) which could develop maximum exciting forces of 5000 pounds continuously and 20,000 pounds for short periods at speeds ranging from 360 to 1500 RPM.

There are two parallel shafts geared together by the two large single-helical gears, one on each shaft, to ensure synchronous rotation of the two main shafts in opposite directions. Each main shaft is driven by a d-c motor through one of two alternate reduction-gear trains with speed ratios of either 6:1 or 16:1. Each shaft carries a 6000-pound eccentric which can be adjusted to various amounts of unbalance. This machine produces a sinusoidal force which is always perpendicular to its base; it is so constructed that the base must always be horizontal or nearly so. The magnitude of the maximum exciting force developed is directly proportional to the amount of unbalance, and varies as the square of the speed of rotation of the main shafts.

PRINCIPLES OF OPERATION

The method used for producing vertical sinusoidal force is well known. The vertical components of the centrifugal force produced by both unbalanced masses add, whereas the horizontal components cancel, because the masses are rotating in opposite directions; see Figure 2. If the resultant

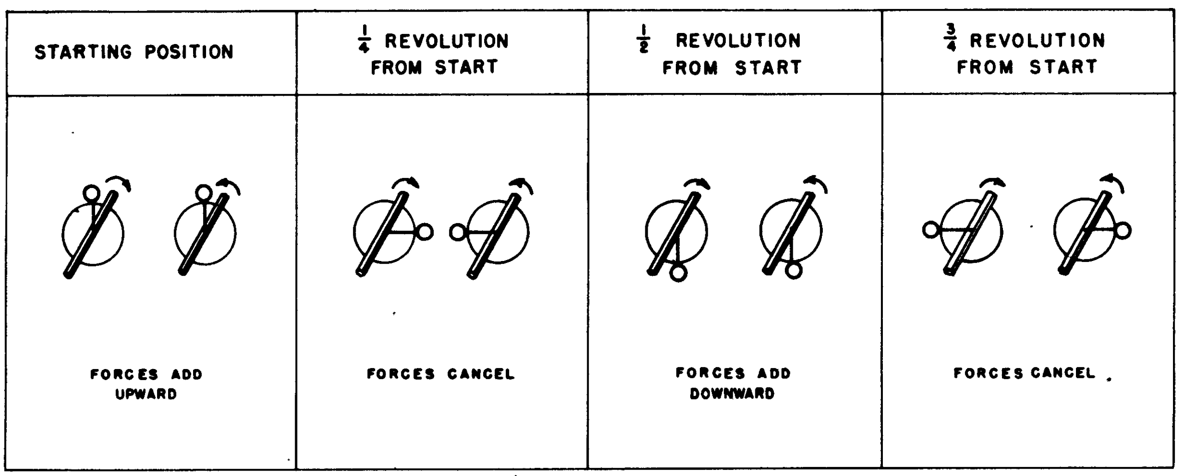

Figure 2 - Diagram Illustrating How Vertical Forces Add and Horizontal Forces Cancel in the 44,000-Pound Losenhausen Vibration Generator

vertical force is plotted on a basis of time the result will be as in Figure 3.

The unbalanced masses of this particular vibration generator must necessarily be large to obtain a large exciting force at a low frequency. The unbalance is variable between zero and maximum to permit a selection in the magnitude of the exciting force available at a given speed.

The weight of this machine is about 49,000 pounds and thus exceeds its maximum rated amplitude of exciting force by 5000 pounds. This, however,

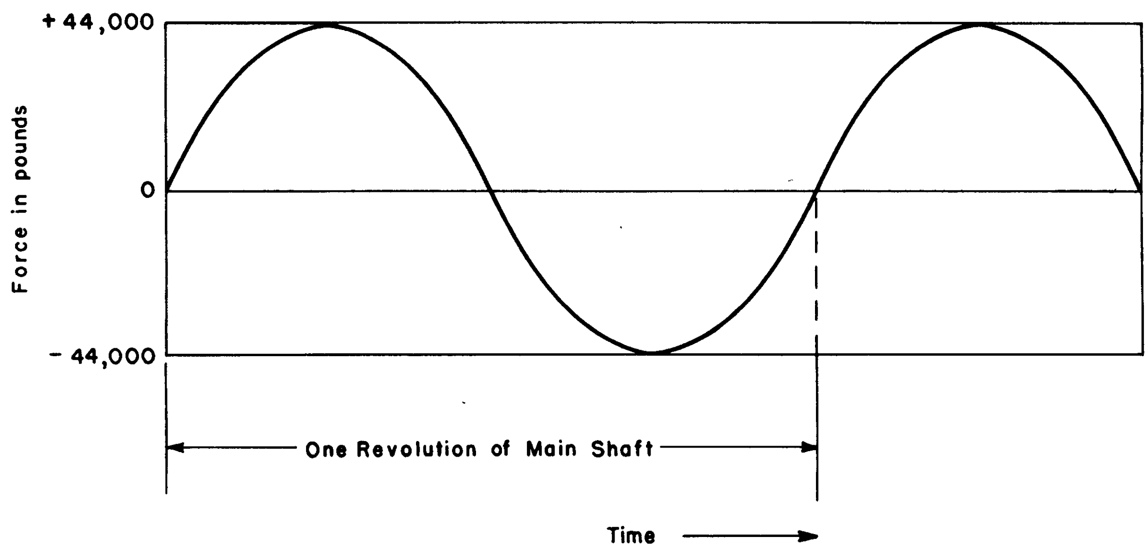

Figure 3 - Diagram Showing Variation of Rated Exciting Force with Time as Produced by the Large Losenhausen Vibration Generator

does not obviate the necessity of fastening the machine down when resonance is anticipated. On board ship it has been the practice to mount the vibration generator on two 12-inch I-beams as shown in Figure 4, and to weld or otherwise secure these to the supporting structure temporarily to ensure that the machine does not change position.

This machine is designed to operate only in the horizontal position shown in Figure 4, and produces only forces perpendicular to its base, that is, vertical forces. The maximum single amplitude of the sinusoidal force developed at 54 RPM is 11,700 pounds. The rated maximum amplitude of force, 44,000 pounds, can be developed at all speeds from 105 to 480 RPM.

The procedure for determining the natural frequencies of a structure consists in mounting the vibration generator, setting a relatively small value of unbalance, and gradually increasing the speed through the speed range. The speeds at which maximum amplitudes occur indicate resonant frequencies. It is then desirable to increase the unbalance, or eccentricity, within the permissible range* and to explore in the resonant frequency ranges to obtain several points on the curve of amplitude against frequency and thus define that curve clearly. The vibrator is then run at resonance while the structure is explored by suitable vibration instruments. This survey enables the investigator to determine definitely the mode of vibration of the structure.

* The data for these ranges are given subsequently within this report.

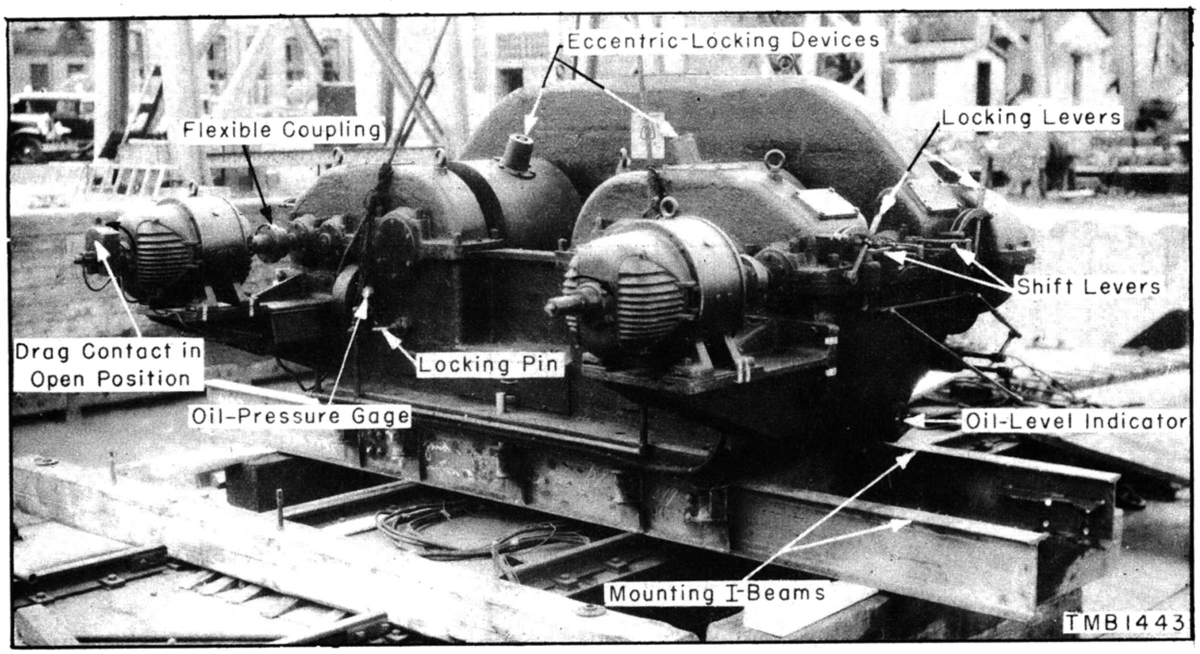

Figure 4 - Front View of Losenhausen 44,000-Pound Vibration Generator

This view shows the machine from the motor side, which is hereafter referred to as the front of the machine. Note the mounting I-beams which are bolted to the vibration generator and are suitable for welding to most test structures.

Two arrows above the motor shafts indicate proper motor rotation. The drag contact pointer on the left motor indicates that the contact is open as it would be when the eccentrics have reversed after stalling during a starting cycle at large eccentricities. One of the four flexible-shaft couplings is plainly shown.

The locking levers and shifting levers are shown at the right in the photograph. Below these levers and near the base of the machine is a round glass window which indicates the oil level in the sump. One of the three oil-pressure gages is shown at the front of the machine. These gages indicate gage pressure in the oil line ahead of the gear boxes.

The locking pins must be engaged before the eccentric-looking devices are unlocked. The left locking pin is visible in the picture.

Whenever practicable, sufficient data are obtained to make possible the plotting of a curve of the power absorbed by a vibrating structure on a basis of the frequency of excitation. Such a curve is shown in Figure 5. The power used by the vibration generator is recorded during the speed survey, corrected for the no-load losses of the machine,* and replotted against frequency to produce a power-resonance curve. From this curve the logarithmic decrement of the structure can be deduced (5). The equation is

$$\delta = \pi \frac{f_2 - f_1}{f_{max}}$$

* The no-load losses at intermediate speeds may be estimated roughly by joining the portions of the power curve above and below resonance by a smooth curve. The broken-line curve shown in Figure 5 was obtained in this manner.

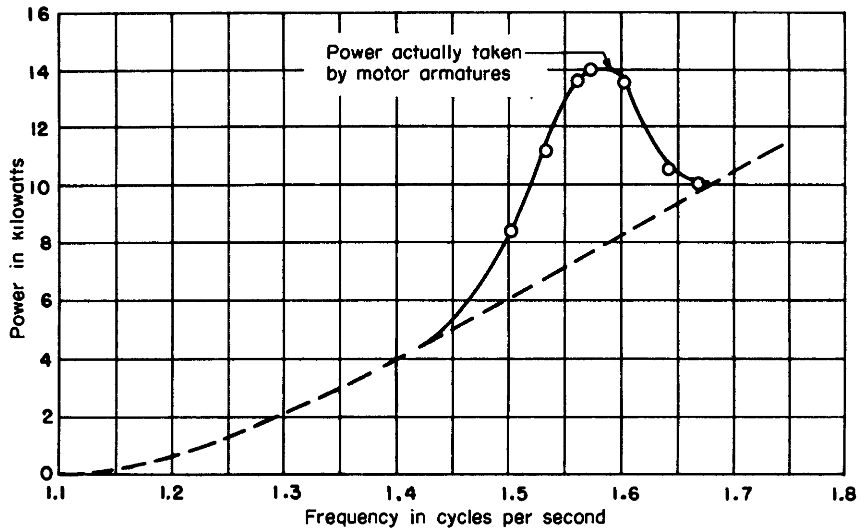

Figure 5 - Curve Showing Power Consumption of the Large Vibration Generator during a Shipboard Test

The broken line shows the power that would have been required at intermediate speeds if the structure had not been in resonance. The excess power demand at resonance is caused by the increased energy absorption both in the ship structure and in the water surrounding the hull.

The data used in plotting this curve were taken during structural tests aboard the SS PHILIP SCHUYLER.

where δ is the logarithmic decrement,

f_1, f_2 are the two frequencies at which the power input to the structure is equal to half the maximum power input to the structure, and

f_{max} is the frequency at which the power input is a maximum.

The ratio of the damping constant to critical damping for small damping ratios (6) is

$$\frac{C}{C_c} = \frac{\delta}{2\pi}$$

COMMON APPLICATIONS

This large vibration generator is used to determine the dynamic characteristics of large structures such as ships and bridges, which have low natural frequencies. In ships it is possible to simulate exciting forces of shaft frequency and to some extent those of blade frequency.* It may be desirable in some cases to mount this vibration generator on the engine foundation and to shake the ship from this position. This shaking will indicate the approximate resonance frequencies which are likely to be excited during operation of the ship.

The resonant frequencies of the hull as well as local resonances can be determined by a survey with vibration meters while the speed of the vibration generator is set on each of a number of selected speeds through the

* Blade frequency is shaft RPM times the number of propeller blades.

speed range. This method offers the opportunity of stiffening or otherwise changing the structure in order to avoid undesirable resonances. Thus it is possible to anticipate and eliminate certain troublesome resonances and deficiences even before the trial runs are made. Hitherto, however, this machine has been used only in tests of completed ships (7) (8), in which it was mounted on the main deck near the bow or the stern rather than on the engine foundation or other structural parts. A photograph of such an installation is shown in Figure 6.

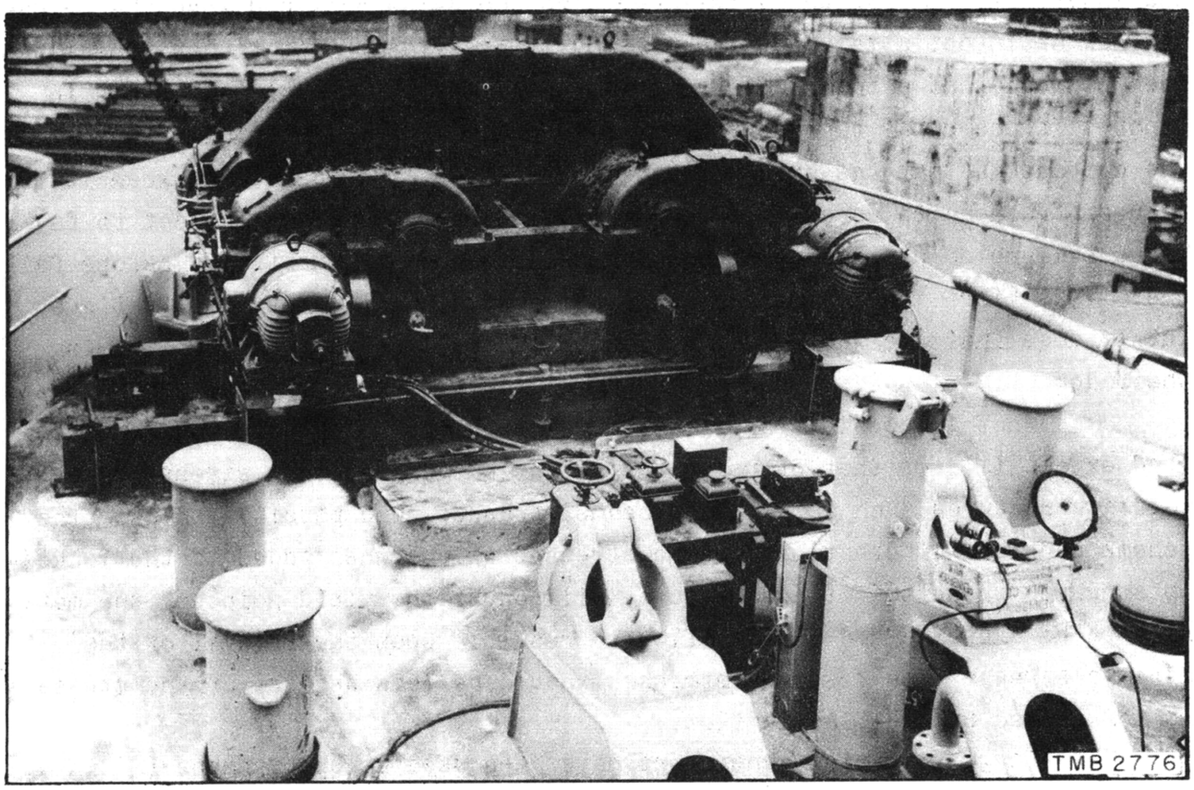

Figure 6 - Photograph of an Installation of the Large Vibration Generator aboard a Ship

On this occasion the machine was mounted in the bow of a tanker, and the mounting I-beams were welded to the deck in the position shown. This is the installation aboard the SS SHILOH.

Another use of this large vibration generator is in exciting the hull of a ship in its lower resonant frequencies and measuring the alternating strains at various stations throughout the ship. This excitation enables the investigator to determine the dynamic stress distribution for the particular mode excited. The amount of stress obtained with any given vibration generator depends upon the damping constant of the structure. In such tests it is preferable to have the vibration generator mounted either at the bow or the stern. In the course of several shipboard tests (7) (9) (10) stresses up to 1000 pounds per square inch single amplitude were obtained.

The machine also has applications in the testing of bridges (2), where it may be used to find the stiffness of a bridge, its effective mass, and its natural frequency. It may even be used to determine the excitation given the bridge from some other source, such as the force produced by the drivers of a locomotive. Vibrating a bridge during periodic inspections is a practical way of determining if there has been a change of stiffness. If the lowest natural frequency is lower than the value obtained when the bridge was new or in definitely good condition, it is evident that the stiffness has been reduced, and a thorough investigation of the structural members is in order. If there has been no change in the values of the natural frequencies, one can assume that the bridge is structurally as sound as it was when its natural frequencies were first determined. However, members subject to fatigue failure do not lose their stiffness until a very short time before failure. This vibration test is not a means of predicting safety from fatigue, but it does indicate whether or not the structural members are still doing their job.

Another possible application which has been investigated to a limited extent (11) is that of using the vibration generator to stress-relieve welded structures such as built-up beams, trusses, and possibly ships. The scheme consists in creating dynamic stresses which, when added to the locked-up stresses present in the structure, will cause the yield point of the material to be exceeded and plastic flow to result. Upon the removal of the dynamic stresses the residual stresses should be less because of the stress relief caused by the plastic flow.

Large vibration generators have been used by the Germans (2) in determining the stiffness of foundation sites and road beds, and eliminating some of the construction and maintenance difficulties due to uneven settling of the soil.

GENERAL FEATURES

This large vibration generator, although bulky and heavy, performs satisfactorily the duty for which it is designed, that is, exciting large structures in their comparatively low natural frequencies. It must be noted, however, that it generates forces only in the direction perpendicular to its base, that is, vertical forces, so that its use is to a certain extent limited.

Three general views of the machine are shown in Figure 7. A horizontal cross section through the main shaft axes is presented in Figure 8.

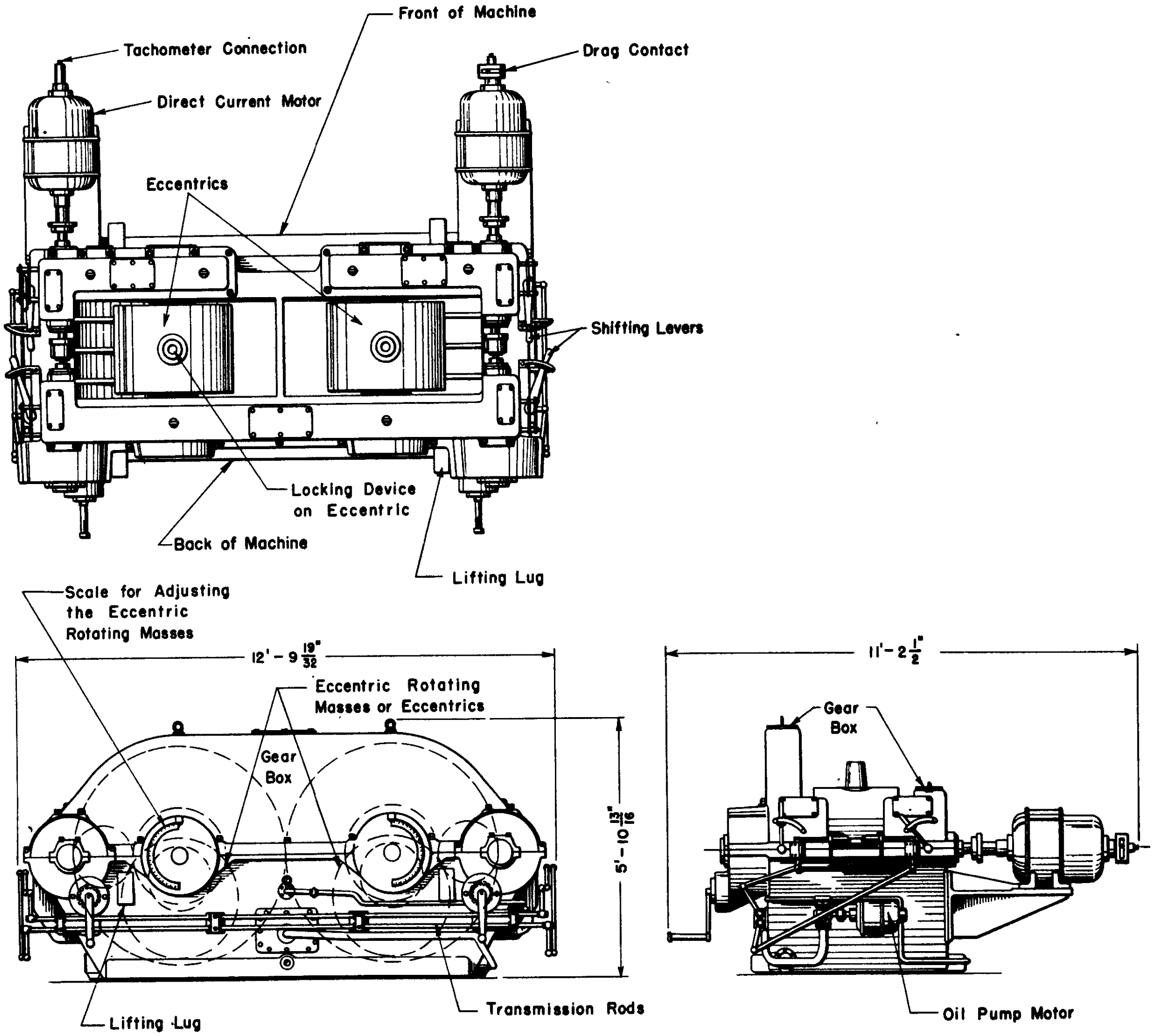

Figure 7 - General Views of the Losenhausen 44,000-Pound Vibration Generator

This vibration generator may be lifted by cables attached at the four lifting lugs. The eyebolts shown at the top of the gear boxes are only for removing the gear-box covers.

The weight as shown is 49,000 pounds.

Labels designate the front and back of the machine as referred to in this report.

The outlines of the eccentric rotating masses are shown as they appear when adjusted to maximum eccentricity.

The power is transmitted from the driving motors to the main shafts by alternate gear trains with a speed reduction of either 16:1 in low gear or 6:1 in high gear. These transmission gears are enclosed in cast-steel housings

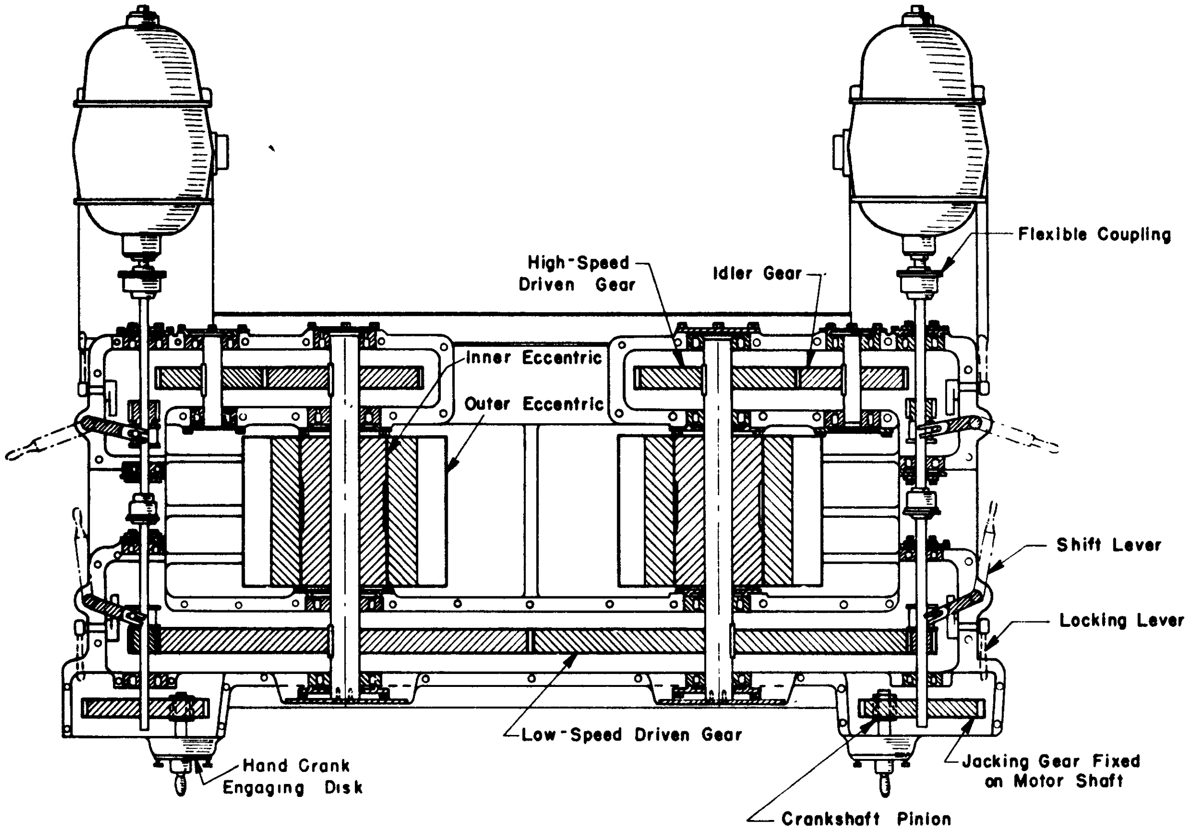

Figure 8 - Horizontal Cross Section through the Shaft Axes

All transmission gears are solid steel disks keyed to the shafts, with single-helical gear teeth cut on the periphery. All shafts are supported by roller bearings.

The connecting links between gearshift levers and the guides for the gear shift and locking levers are not shown in this view.

split on a horizontal plane through the main shafts. The upper half of each of these housings may be lifted by the eyebolts visible in Figure 7.

Each motor shaft has two flexible couplings to allow for any slight misalignment. The driving pinions are mounted on motor shafts having a splined portion, which permits the speed ratios to be changed by shifting one or the other pair of pinions. Connecting links between shift levers prevent the driving motors from being connected to the main shafts by both gear trains simultaneously. The high-speed and low-speed driven gears are fixed on the main shafts. The low-speed driven gears are in mesh with each other, thus connecting the main shafts and ensuring synchronous rotation of the eccentric assemblies. All transmission gears are of the single-helical type. The crankshaft pinions and jacking gears are of the spur type. The main shafts are supported by roller bearings, which are lubricated by grease fittings.

The motor shafts are also supported by roller bearings, but the lubrication of these bearings is by splash lubrication from the transmission gears.

The eccentric assemblies each comprise two eccentrics, one inside the other. The inner one is a disk eccentrically and rigidly mounted on the main shaft, and the outer one is a disk with a hole eccentric with respect to its center. The characteristic eccentricity of both disks is 5.9 inches; see Figure 9. Relative rotation between these inner and outer disks causes the center of gravity of the assembly to move toward or away from the shaft axis.

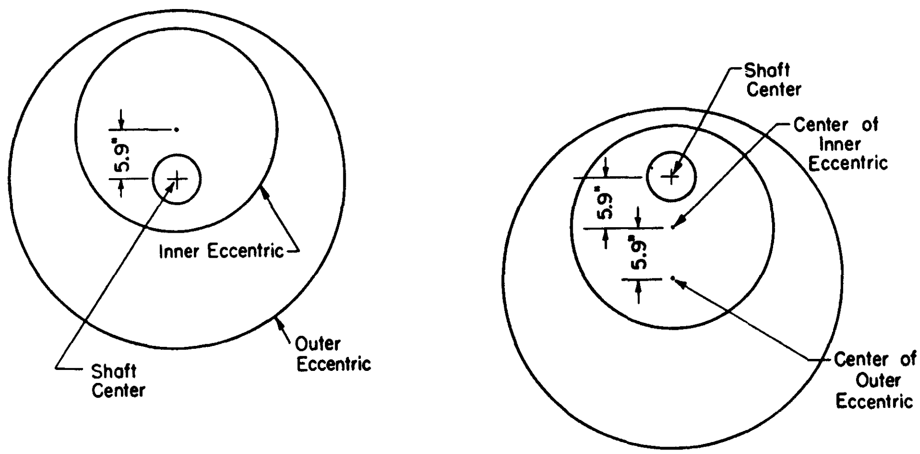

Figure 9a - Balanced Position

Figure 9b - Position of Maximum Unbalance

Figure 9 - End Views of an Eccentric Assembly Showing the Scheme Used to Obtain Variable Eccentricity of the Rotating Mass

Figure 9b shows the position of maximum unbalance which is obtained by rotating the inner eccentric 180 degrees with respect to the outer eccentric when starting from the balanced position illustrated in Figure 9a.

Maximum unbalance is obtained when the relative rotation is 180 degrees from the balanced position. Since each eccentric assembly weighs 6000 pounds, and the maximum eccentricity of the shaft center with respect to the center of gravity of the assembly is 11.8 inches, the unbalance is variable from zero to 70,800 inch-pounds. A cross section of an eccentric assembly is shown in Figure 10.

The eccentric assemblies are exposed, and the locking devices are accessible from the top of the machine; see Figure 4 on page 5. The outer eccentric can be unlocked with respect to the inner eccentric by turning the head of the locking bolt counterclockwise. The actual adjustment is made by securing the outer eccentrics in position with respect to the frame by locking pins, and rotating the main shafts, and hence the inner eccentrics, by the hand cranks visible in the photograph in Figure 11. An angular scale is

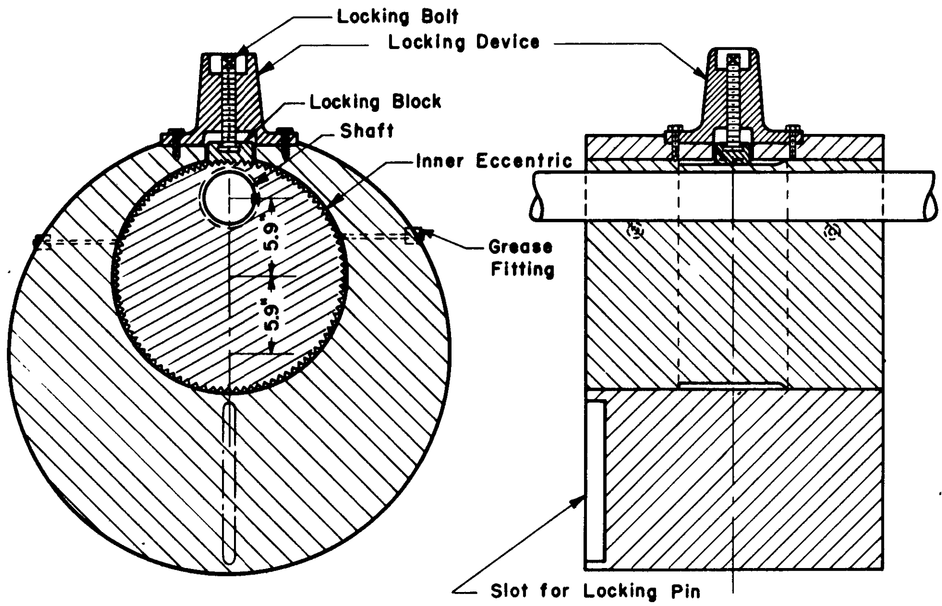

Figure 10 - Sectional Views of One Eccentric Assembly Showing the Locking Device

The locking bolt which advances the locking block toward the surface of the inner eccentric has a square end which is turned by a T-handle socket wrench. There are four grease fittings which grease the bearing surface between inner and outer eccentrics. The eccentric assembly is shown in the position of maximum unbalance.

attached to the crank end of each main shaft. When the cranks are engaged, and when the outer eccentrics are secured by the locking pins in the proper fashion, the pointers attached to the frame indicate the actual index setting on their respective scales. The eccentricity is defined by this index setting.*

The main shafts are driven by two similar compound-wound d-c motors having series interpoles to provide better commutation. Each motor is rated at 15 kilowatts (20 horsepower) at speeds from 800 to 3000 RPM. These two motors are connected in parallel to a 220-volt d-c power source.

Principal engineering data are summarized as follows:

Overall dimensions	Length 12.80 feet Width 11.21 feet Height 5.90 feet
Total weight of generator only	49,000 pounds
Weight of control apparatus	500 pounds
Weight of each eccentric assembly	6000 pounds
Speed range:	
In low gear	54 to 180 RPM
In high gear	150 to 480 RPM

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* See Table 1 on page 21.

Rated power of each driving motor	15 kw (20 HP)
Maximum armature current	200 amperes
Length of cables from control apparatus to vibration generator	25 feet (can be lengthened)
Eccentricity	$2R \sin \frac{\alpha}{2} = 11.8 \sin \frac{\alpha}{2}$
Maximum eccentricity	11.8 inches
Eccentricity variable in 3-degree increments	0 to 180 degrees
Maximum driving force at 54 RPM (lowest running speed)	11,700 pounds
Speed range at which rated driving force can be developed	105 to 480 RPM (1.75 to 8.0 CPS)

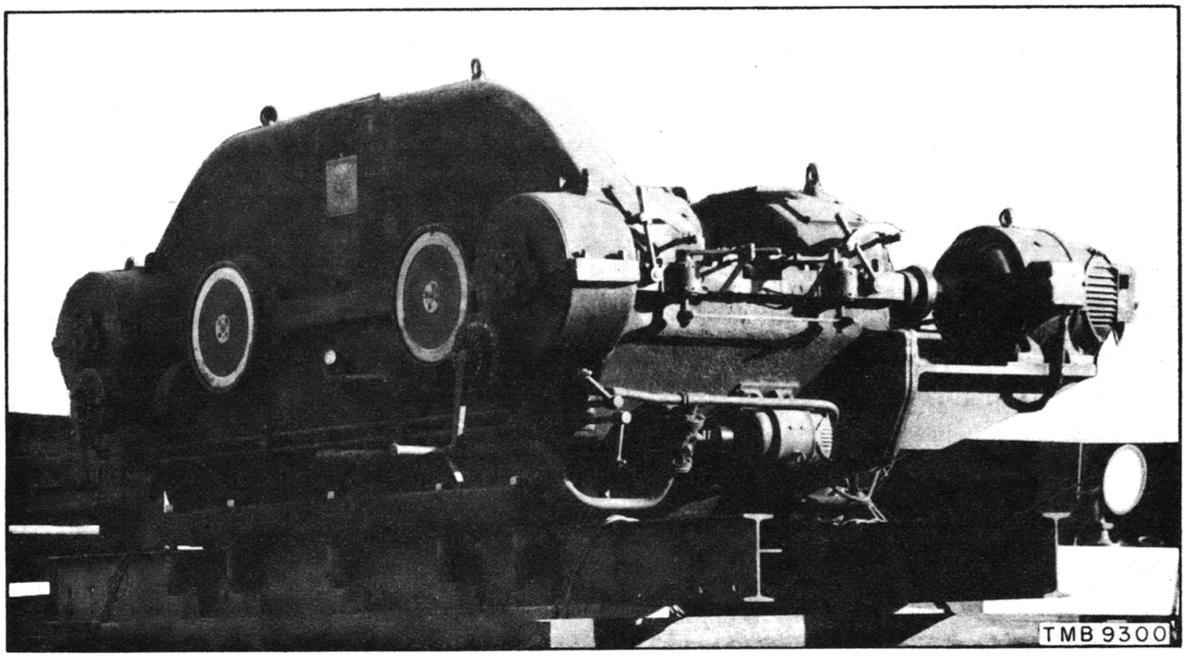

Figure 11 - View Showing the Back of the Losenhausen 44,000-Pound Vibration Generator

The oil-pump motor is visible at the right end of the machine below the gearshift levers but above the mounting I-beams. The angular scales on the back of the machine can be seen. The rods running the length of the machine below the scales are the long connecting links between gearshift levers. The short links on the side of the machine were not attached to the gearshift levers when the photograph was taken.

LUBRICATION

The gear trains have force-feed oil lubrication. Oil thrown from the gears is used also to lubricate the bearings supporting the motor shafts. The amount of oil necessary to fill the sump to the required level to maintain oil pressure is 40 gallons. Navy Specification 2135 is a satisfactory lubricating oil for this machine. The oil level should be above the halfway mark on the glass oil-level indicator shown in Figure 4. Three pressure gages serve to indicate the oil pressure in the system in atmospheres. The pressure during operation should be about one atmosphere gage.* Two gages are located on the front and one on the back of the machine - all are near the entrance of the oil line into the gear case.

The main shafts of the machine are supported by roller bearings and are lubricated through grease fittings. The surface between inner and outer eccentrics is also lubricated through special grease fittings with a special grease gun that belongs to the machine. All grease fittings should be greased after approximately 50 hours of continuous operation of the machine.

ELECTRICAL CONNECTIONS

This machine is driven by two special compound-wound motors with series interpoles. They are connected in parallel to a d-c source of 220 volts. The operating speed of these motors is controlled by varying the resistance in series with the shunt fields.

The main electrical control apparatus is shown in Figure 12, and the schematic wiring diagram of the electrical system is shown in Figure 13. When the machine is being started, the main control gradually cuts out the resistance that was initially in series with the armature as the arm attached to the main control handwheel, Figure 12, is moved up to Position 14. The speed is regulated while the vibration generator is in operation by varying the shunt field voltage. Positions numbered above 14 on the main control handwheel give the coarse speed adjustment, and the handwheel to the left of the main control handwheel gives the fine speed adjustment; see Figure 12.

The direct-current power supply should have a capacity of 30 kilowatts at 220 volts and should be connected to terminals "N" (negative) and "P" (positive) on the panel at the rear of the controls. Connecting cables, if longer than those provided, should be capable of carrying 200 amperes with a drop of not more than 20 volts.

A glance at the schematic wiring diagram, Figure 13, shows that the system is complicated by numerous safety devices. All of these must be in the proper positions before the main switch, which is electromagnetically operated, will close. First of all, the starting rheostat of the pump motor must be in running position, where it closes a contact. This ensures that the gears are receiving lubrication if the lubricating-oil system is working properly. The contacting tachometer closes a contact only after the motors

* Since the faces of these gages are graduated in terms of "atmospheres," the gage readings during operation should be about one. This represents an absolute pressure of 2 "atmospheres" or one "atmosphere" gage pressure.

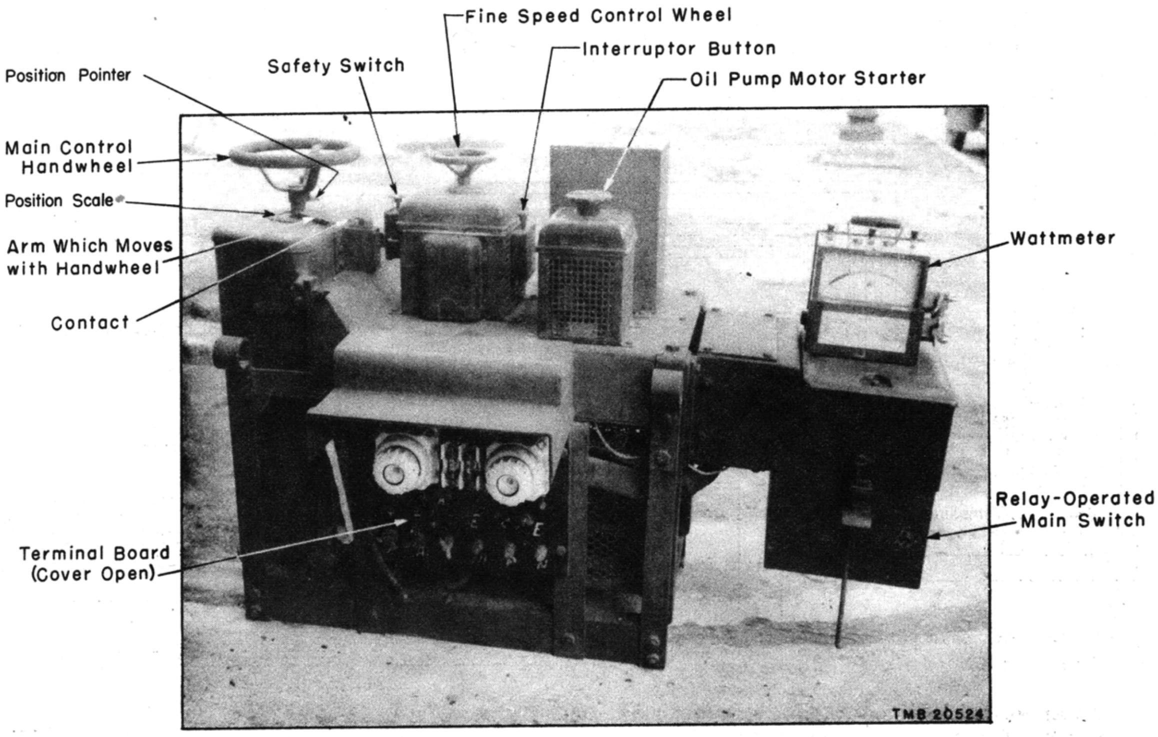

Figure 12 - Photograph of Controls for Vibration Generator

The oil-pump motor is started by turning its starter rheostat clockwise as far as possible. When the main control handwheel is turned clockwise to Position 5 on the scale, the contact arm depresses the contact beside the handwheel, and the relay-operated main switch at the right closes if the various devices on the machine are in proper position. Positions 5 to 14 at the main control handwheel are armature resistances which should be traversed within a minute after the eccentrics have stopped oscillating and have begun to rotate. Positions above 14 are series resistances in the shunt field and are used to produce coarse speed control under running conditions. Fine speed control is obtained by the handwheel immediately to the right of the main control handwheel.

The wattmeter is shown on top of the main switchbox. Speed is indicated by a tachometer not shown. On the tachometer large numbers are read when the machine is in low gear, and small numbers when it is in high gear.

have reached a speed of approximately 800 RPM. This device is generally not used, however, as it has been found unnecessary when the machine is operated with due care. In this case Terminals 1 and 2 are bridged.

When the eccentrics are adjusted for large amounts of unbalance, the motors cannot turn them over top dead center directly from the rest position at bottom dead center. To accomplish this with the comparatively small motors used, a drag contact is utilized. The drag contact is mounted on the motor at the left in Figure 6 and has a contact in series with the operating relay of the main switch. This contact is closed when the left motor shaft is rotating in a counterclockwise direction. When this shaft reverses its direction of rotation, that is, when it stalls because the eccentrics cannot

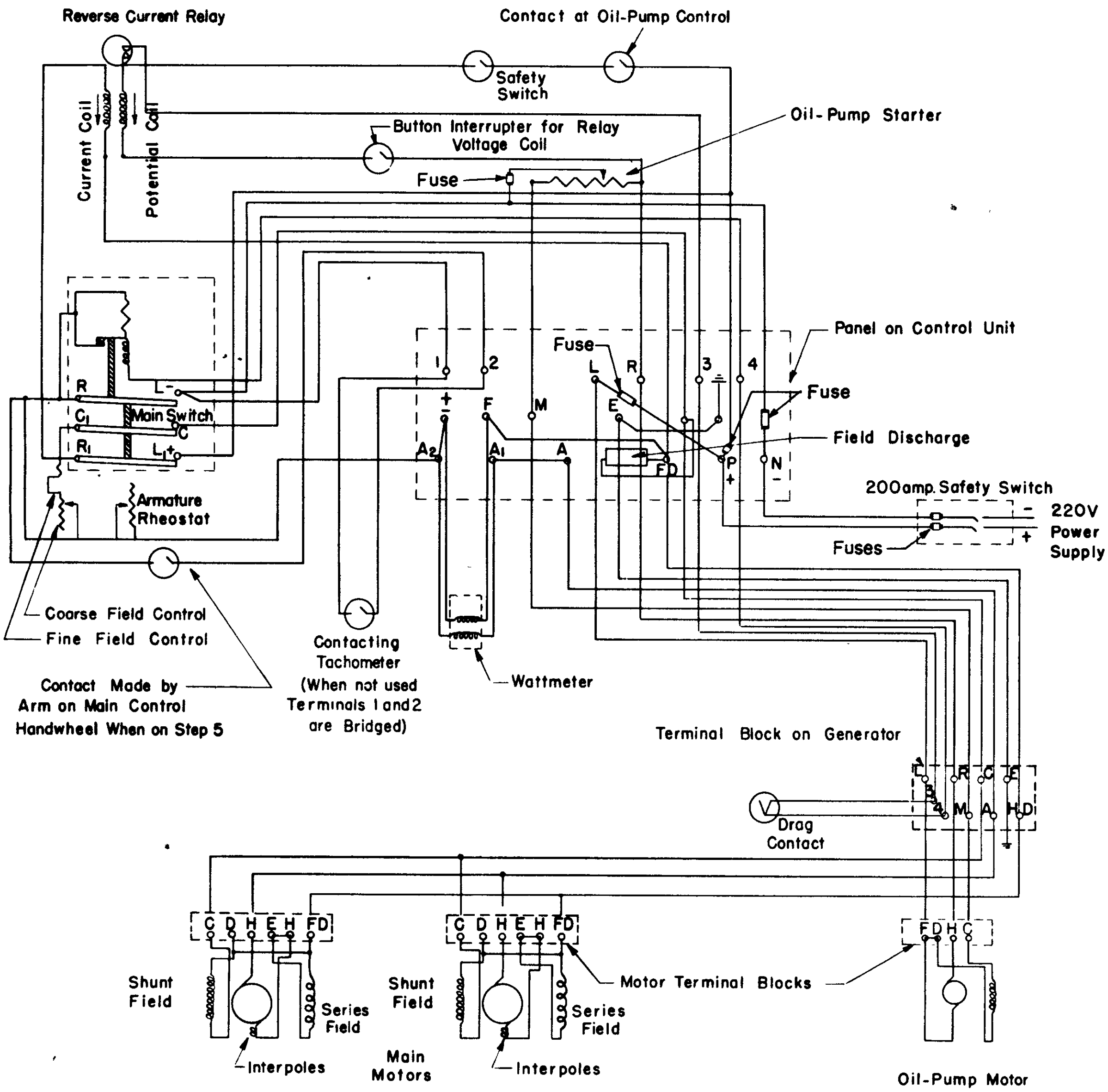

Figure 13 - Wiring Diagram of Generator and Control Apparatus

When the contact tachometer is not used, Terminals 1 and 2 are bridged with cable capable of carrying the armature current; when the wattmeter is not used, Terminals A_1 and A_2 are also bridged. Notice the numerous devices that must be positioned properly before the electromagnetically operated main switch will close.

be lifted any higher, the drag on the shaft opens the contact, as explained subsequently; this causes the main switch to open. The motor torque then drops to zero, and the eccentrics are allowed to swing back freely like pendulums. The motors actually reverse their rotation before the main switch is opened because the kinetic energy stored in the moving parts swings the eccentrics above the point where the motor torque equals the moment produced by the eccentrics. Consequently the eccentrics fall back toward their equilibrium positions, and this motion is used to open the drag contact. As they again begin to swing in the proper direction of rotation, because of having swung beyond bottom dead center, the drag contact closes and motor torque is applied until the motors are again reversed. These switching cycles take place until enough energy is accumulated in the swinging eccentrics to enable them to swing over top dead center and continue to rotate in the proper direction.

To protect the circuit against excessive current flow in reverse direction caused by the back electromotive force induced when, in slowing down, the field is too rapidly strengthened by moving of the coarse field control, a breaker is inserted which automatically throws the main switch when the reverse current approaches a certain limit. This limit can be varied by adjusting the tension of the spring which restrains the relay from making the contact. If this breaker has closed, it will remain in that position until the voltage in the relay coil is broken by the button interrupter; see Figure 13. This button is not visible in the photograph of the panel in Figure 12 but is located between the oil-pump-motor starter and the fine speed control wheel. The main control handwheel must be on Position 5 to make the final contact and thus to cause the main switch to close. A "safety" switch, the red button near the main control handwheel, is provided for emergency stops. When this is depressed, it breaks the armature and field circuits simultaneously by opening the main switch. This switch is generally used to stop the machine, and a field discharge has been installed across the motor fields to protect them from current surges; see Figure 13.

The wattmeter current connections should be connected between Terminals A_1 and A_2 on the control panel. If the wattmeter is not used, these terminals must be short-circuited with cable capable of carrying the armature current, 200 amperes maximum. Voltmeter connections to the wattmeter are made on the terminals marked positive and negative immediately above the current connections on the control panel.

SPEED CONTROL AND TACHOMETER

This machine has a satisfactory stable speed control provided the power supply has a steady voltage. Since the motors are geared down by a ratio of either 6:1 or 16:1, speed control can be accomplished by a conventional method of d-c motor control. This method was dealt with in the previous section.

The vibration generator speed at any instant is given by a precision tachometer which indicates the speed in revolutions per second. The dial has two scales to correspond to the two gear ratios; the scale with the large numbers is read when the transmission gear ratio is 16:1, and the scale with the small numbers is read when the 6:1 transmission gear ratio is used.

The tachometer shaft is driven from the free shaft end of one of the motors, hence the necessity of two scales on the tachometer face. The tachometer cable should be kept straight because any sharp bends in it are liable to break the flexible shaft.

INSTALLATION INSTRUCTIONS

The vibration generator must be rigidly attached to the structure under test if its exciting force is to be utilized properly, even though its weight does exceed its rated driving force by 5000 pounds. Two 12-inch structural I-beams have been made up, for bolting to the foundation of the machine; they are visible in Figure 6. These serve as a convenient footing which can be tack-welded in place on steel structures. Since the dead weight of this machine is 49,000 pounds and the permissible peak value of the alternating force it can produce is 44,000 pounds, the load applied to a structure can range from 5000 to 93,000 pounds. Therefore it is nearly always necessary to reinforce the portion of the ship or structure under this concentrated load, otherwise much of the energy delivered will be expended in deforming the local structure instead of shaking the structure as a whole.

This heavy machine has been mounted and used on the forecastle of a World War I destroyer, the HAMILTON (7), by blocking under the foundation I-beams to the camber of the deck and by temporary shoring and stiffening for two deck heights below the generator.

Naturally, because of its weight and size and the machinery attached to it, this machine should be handled only by experienced riggers. It should be lifted by the lugs on the side of the machine, shown in Figure 4, using a bight of wire rope of not less than one inch diameter under each lug. As previously pointed out, the eyebolts on the top of the machine are intended only for removing the top part of the gear housing. If the space or load-carrying facilities are limited, it is possible (but not convenient) to remove the motors and their supporting brackets and transport them separately. Ordinarily this has not been found to be necessary.

It is desirable to install sound-power telephones so that the technician making vibration measurements around the structure may talk to the operator of the machine while the test is underway.

OPERATING INSTRUCTIONS

Operating instructions are set down in detail to give the person who is relatively unfamiliar with the machine explicit procedures to follow.

SETTING THE ECCENTRICITY

The angle of setting, and hence the eccentricity, can be changed only by rotating the inner eccentric with respect to the outer eccentric.

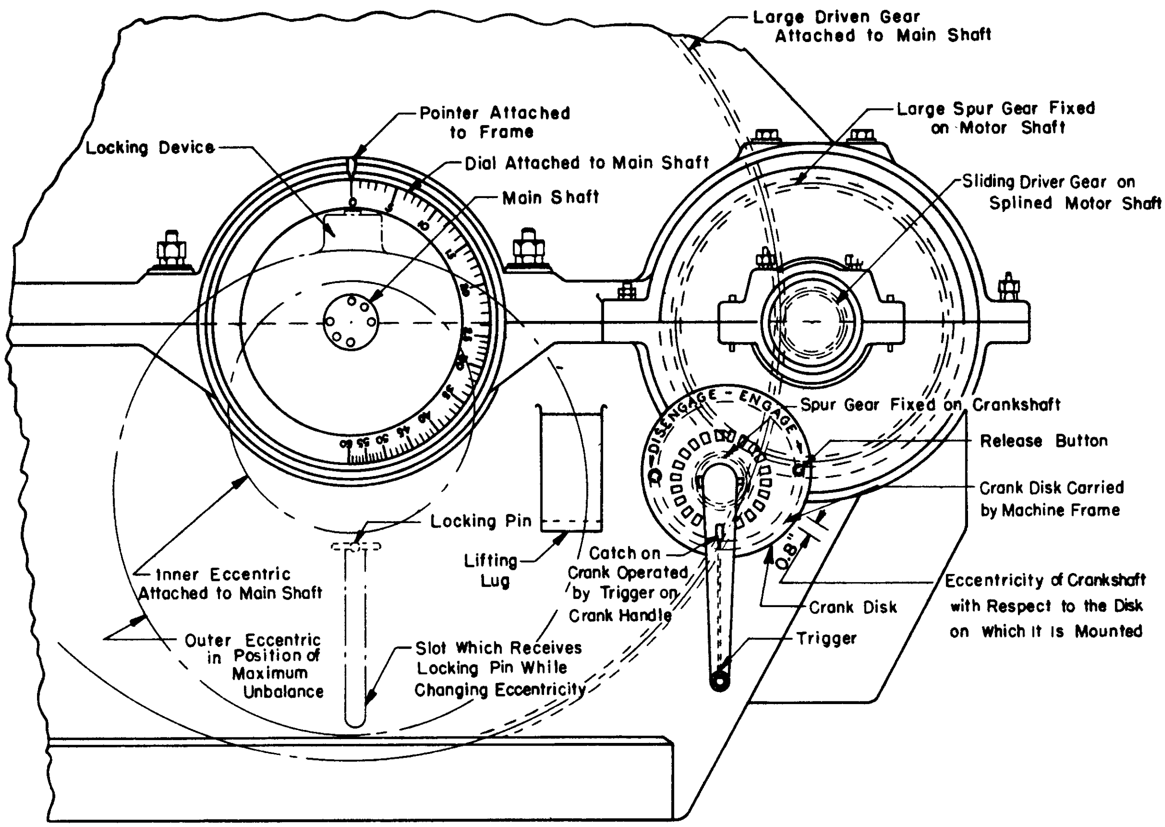

Figure 14 - Diagram of Portion of Losenhausen 44,000-Pound Vibration Generator Showing Mechanism Used to Change Eccentricity

This view shows the right portion of the machine as viewed from the back. The view of the left portion is similar but to the opposite hand.

The large gear fixed on the end of the motor shaft and the crankshaft pinion that meshes with it are of the spur type. The profile of the eccentric assembly is shown for the maximum eccentricity, which occurs at an angle of setting of 180 degrees from balanced position. This corresponds to an index setting of 60 indicated on the dial. The locking pin indicated is operated from the opposite side of the machine and must be in the slot in the outer eccentric before the locking device is loosened.

The cranks are usually removed during shipping as they can be broken quite easily during handling of the machine.

Several men and several operations are necessary to make this change.

The following discussion is based on Figure 14, showing the right side of the back of the machine. Operations performed on the left side will be to the opposite hand. The recommended procedure follows.

1. Place the machine in low gear, because the cranks then have maximum mechanical advantage.

2. Press the release button at the right of the crank disk as shown in Figure 14. This pushes a spring-loaded locking pin out of the crank disk and into its recess in the machine frame. It is then possible to rotate the crank handle 180 degrees in the direction marked "engage" *without* pressing

the trigger in the handle. This rotates the crank disk until the other hole is opposite the spring-loaded pin, and the pin automatically locks the disk in position. Since the crankshaft center C is eccentric with respect to the center of the disk D, this 180-degree rotation advances the crankshaft pinion approximately 1.6 inch toward the gear fixed to the motor shaft and thus causes the two gears to mesh.

3. Squeeze the triggers on both crank handles at the same time and rotate the eccentric masses by turning the cranks simultaneously until the locking pins on the opposite end of the machine are in line with the slots in the outer eccentrics. This positioning occurs when the pointer on the dial indicates the existing index setting. When the pins are opposite the slot in the face of the outer eccentrics, the pins can be pushed inward and turned 90 degrees to lock them against the compression release springs. It is *important* that these locking pins be inserted in the slots; this should be checked by trying to rotate the cranks with the triggers depressed before the locking devices are loosened. If they rotate more than a few degrees in either direction the pins are not engaged properly. In checking this point, only a little force should be applied to the cranks to avoid the possibility of shearing these pins.

4. After locking the outer eccentrics with the locking pins, loosen the eccentric-locking devices by the T-handle wrench; see Figure 10. The wrench must be turned at least four complete turns counterclockwise to unlock this device completely.

5. Change eccentricity by having the operators squeeze the triggers on the crank handles and rotate them simultaneously until the pointer on the dial indicates the desired index setting. Releasing the trigger automatically locks the crank with respect to the crank disk.

6. To lock the inner and outer eccentrics with respect to each other the locking bolt must be turned clockwise by the T-handle socket wrench. The locking device on the left, when the machine is viewed from the front, must be turned 5 turns, the other 4 1/8 turns, from fully unlocked position. If the teeth on the locking bolt do not mesh properly with the teeth on the inner eccentric, the device will seem to be tight before the required number of turns have been made. When the teeth fail to mesh, the device should be loosened, and the cranks rotated a few degrees back and forth while the device is tightened again.

7. The locking pins may now be released by turning them approximately 90 degrees again, until they spring outward. The cranks may have to be moved slightly to allow these pins to disengage. The operators handling the cranks

should be aware that the eccentric masses will try to return to their lowest position when the locking pins are released; they should be ready to ease them back to the low dead-center position gradually. When the index setting is about 40, corresponding to an angle of setting of 120 degrees, this moment is the greatest; it decreases toward either end of the scale.

8. The cranks can then be disengaged by pushing the release button that projects out from the disk, and rotating the disk 180 degrees until the spring-loaded pin again secures the disk.

Table 1 shows the speeds at which rated force is developed for a given index setting. In addition it lists for each index setting the corresponding value of the angle of setting, the eccentricity, and the value *K*. If *K* is multiplied by the square of the speed in cycles per second, the product will be the single amplitude of the total force generated in pounds. The curves in Figure 15 are useful for estimating required settings for certain speeds and forces.

TABLE 1

Tabulation of Pertinent Data for the
Losenhausen 44,000-Pound Vibration Generator

Index Setting	Angle of Setting α degrees	$r = 2R\sin\frac{\alpha}{2}$ inches	$K = m_e r 4\pi^2$ lb-sec²	Upper Speed Limit CPS	Index Setting	Angle of Setting α degrees	$r = 2R\sin\frac{\alpha}{2}$ inches	$K = m_e r 4\pi^2$ lb-sec²	Upper Speed Limit CPS
1	3	0.309	379	8.00	31	93	8.60	10,540	2.05
2	6	0.616	756	7.65	32	96	8.765	10,760	2.02
3	9	0.925	1,135	6.25	33	99	8.97	11,000	2.00
4	12	1.232	1,513	5.40	34	102	9.17	11,250	1.98
5	15	1.540	1,890	4.84	35	105	9.36	11,480	1.96
6	18	1.845	2,265	4.43	36	108	9.55	11,720	1.94
7	21	2.140	2,625	4.10	37	111	9.72	11,920	1.925
8	24	2.45	3,008	3.84	38	114	9.90	12,140	1.91
9	27	2.76	3,380	3.60	39	117	10.07	12,340	1.89
10	30	3.06	3,750	3.44	40	120	10.22	12,540	1.87
11	33	3.35	4,110	3.27	41	123	10.38	12,730	1.86
12	36	3.645	4,470	3.14	42	126	10.51	12,900	1.85
13	39	3.935	4,830	3.02	43	129	10.66	13,080	1.84
14	42	4.225	5,185	2.91	44	132	10.78	13,220	1.83
15	45	4.510	5,540	2.83	45	135	10.90	13,380	1.82
16	48	4.80	5,880	2.74	46	138	11.02	13,520	1.81
17	51	5.07	6,220	2.66	47	141	11.13	13,670	1.80
18	54	5.35	6,560	2.59	48	144	11.22	13,780	1.79
19	57	5.635	6,910	2.53	49	147	11.32	13,900	1.78
20	60	5.89	7,230	2.47	50	150	11.40	13,980	1.78
21	63	6.160	7,550	2.42	51	153	11.48	14,090	1.77
22	66	6.42	7,880	2.37	52	156	11.54	14,170	1.77
23	69	6.685	8,200	2.32	53	159	11.60	14,220	1.76
24	72	6.93	8,500	2.28	54	162	11.66	14,300	1.76
25	75	7.18	8,810	2.24	55	165	11.70	14,350	1.75
26	78	7.415	9,100	2.20	56	168	11.73	14,400	1.75
27	81	7.66	9,400	2.17	57	171	11.77	14,430	1.75
28	84	7.89	9,680	2.13	58	174	11.79	14,470	1.75
29	87	8.115	9,960	2.10	59	177	11.80	14,480	1.75
30	90	8.33	10,220	2.07	60	180	11.80	14,480	1.75

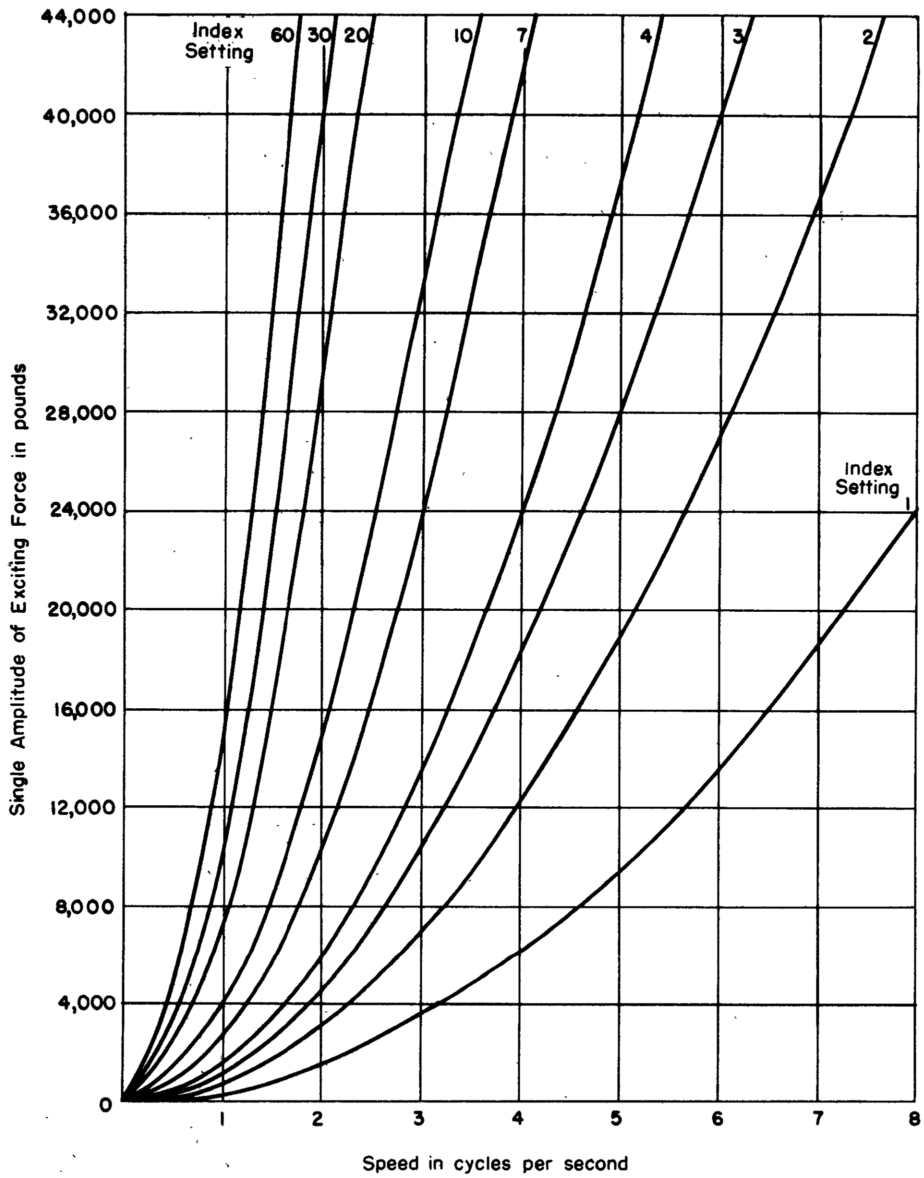

Figure 15 - Single Amplitude of Generated Force Plotted on a Basis of Speed in Cycles per Second for Various Values of Eccentric Settings

The angle of setting in degrees is three times the number of the index setting.

CHANGING MOTOR-ECCENTRIC SPEED RATIO

Two gear ratios are available to extend the range of speeds possible with conventional motor control. The low-gear transmission is located near the crank end of the machine; the high-speed gears are near the motor end; see Figure 8 on page 10.

Figure 16 is a sketch of the gearshift arrangement on one side of the machine. The other side is similar and the corresponding horizontal levers on the two sides are joined by transmission rods as seen in Figure 11. The horizontal levers are used to shift the gears; the vertical levers are designed to lock the shift levers in position. When the low-speed sliding driver gear is in mesh with the larger driven gear, the speed reduction is 16:1 and horizontal shift levers near the back of the machine are in "ON" position. Similarly the horizontal levers on the front of the machine are in "ON" position when the machine is in high gear; the speed reduction is then 6:1.

Gears *must not* be shifted while the driving motors are running. In addition, the cranks used to change eccentricity must be disengaged because the motor shaft must be permitted to turn a few degrees while the helical gears are meshing. All vertical levers should be in "OFF" position while gears are being shifted. Two men, one on each side of the machine, are needed to shift the corresponding gear levers simultaneously since they are interconnected by transmission rods. The sliding driver gears in mesh should be disengaged before the shifting to the next gear ratio. The slotted connecting link between the low-gear shift lever and the high-gear shift lever permits both these gear trains to be in neutral position simultaneously but prevents their being in mesh at the same time. Consequently each operator needs to handle only one lever at a time. Before the shift lever is moved, the handle should be pushed axially to unlock the lever handle from the lever guide. It may be necessary when shifting gears to turn the motor shaft slightly to allow the gear and pinion to mesh without interference. After the gears are shifted to give the desired ratio all the vertical levers should be moved to "ON" position; this locks the shift levers in their respective positions.

If all gearshift levers are in "OFF" position the gears are in neutral and the driving motors can be started to check electrical connections and rotation. They should not be run unloaded more than a few seconds, however, because they are direct-current machines hooked in parallel and then will begin hunting.

STARTING PROCEDURE

Before starting the machine be sure that

1. The locking pins for preventing rotation of the outer eccentrics are disengaged.

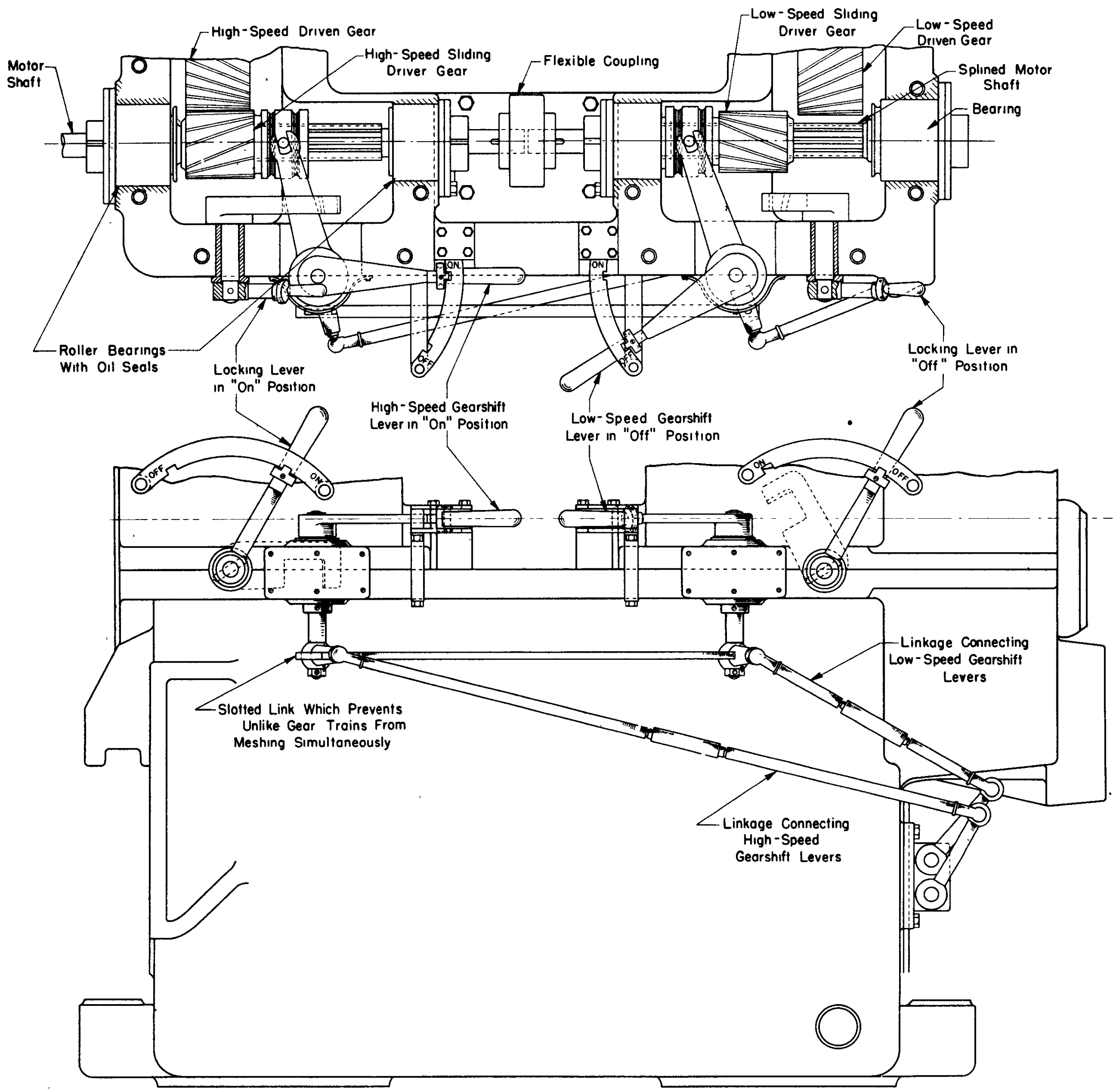

Figure 16 - Diagram Showing Gearshift Arrangement

The plan view at the top shows the arrangement as it would be seen if this end of the machine were viewed from above with the top half of the housing removed and if the gearshift mechanism were left in position. The guides for the locking levers are not shown in this view.

The elevation shows this side of the machine as it would appear when viewed from the side. Note particularly the slotted link which prevents unlike gear trains from meshing simultaneously but allows both gears to be disengaged at the same time.

Gears ***must not*** be shifted when the motors are running.

2. The hand cranks are disengaged; test by determining whether cranks will rotate freely without turning the main shafts.

3. The T-handle socket wrench has been removed from the eccentric locking device.

4. All electrical connections are correct and the safety switches are in.

After the foregoing points have been checked, and the line voltage is applied to the control panel, the oil-pump motor should be started and run for several minutes. The main control handwheel is then turned clockwise until the arm attached to the handwheel closes the contact; see Figure 12.

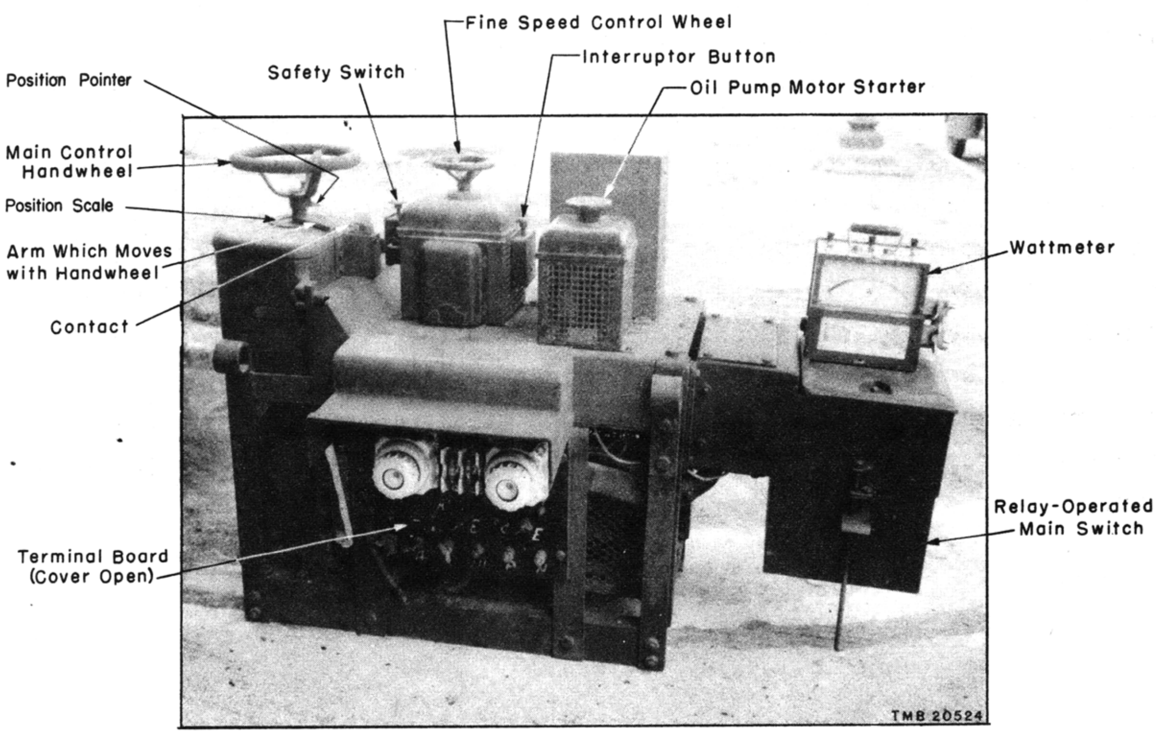

Figure 12 - Photograph of Controls for Vibration Generator

This contact is made at Position 5; where it closes the main switch; the eccentrics should then begin oscillating in pendulum fashion if the machine is set at high eccentricities, or should begin to rotate if eccentric settings are comparatively low. If they do not oscillate or rotate, the pointer in the drag contact on the left-hand motor should be pushed to the left, as that is its proper position for starting. After the main switch has been closed and the eccentrics are rotating continuously in the proper direction, the main handwheel should be brought up to Position 14 in the space of a minute or so, as the circuit still has resistance in series with the armature. This resistance is designed for starting only and cannot carry the armature current under continuous operation. Higher speeds are then obtained by means of the main handwheel positions above Position 14, and for speeds between the coarse control positions the fine control setting is varied; see Figure 12. The speed setting should not be changed from one position to the next without allowing the wattmeter to settle down to a steady reading.

ACCESSORIES

A wattmeter capable of measuring the power input to the driving motors is supplied with the machine. One division on the face of this meter indicates 400 watts when the 250-volt scale is used, making a full-scale deflection of 125 divisions equal to 50 kilowatts.

The tachometer, which indicates the speed of the eccentrics in revolutions per second, is shown in Figure 6 on page 7. Since it is driven from the shaft of one of the driving motors it necessarily must have two scales to correspond to the two possible gear reductions. The inner scale with the large numbers from 0 to 35 cycles per second is read when the machine is in low gear, 16:1 gear ratio, and the outside scale with numbers from 0 to 8.0 cycles per second corresponds to the high gear, ratio of 6:1.

A special grease gun is provided to grease the fittings on the eccentric assemblies. The fittings on the main shafts are of a different size than those on the eccentrics, so that a separate gun fitting is necessary.

TOOLS

The only tool necessary for operation is a T-handle socket wrench for use on the eccentric locking devices.

OPERATING PERSONNEL

Any test requires the services of at least two technicians, one of whom can explore the structure with vibration instruments while the other remains at the controls of the machine. It is necessary that they be able to communicate with one another during the test. One of the best methods of doing this is by sound-power telephone. Three or more operators are required to change gears and to change eccentricity.

REFERENCES

(1) "Rein dynamische Verfahren zur Untersuchung der Beanspruchungen von Bauwerken" (Purely Dynamical Methods of Investigating Structural Stresses), by R. Bernhard and William Späth, Der Stahlbau, Vol. 2, No. 6, March 22, 1929, pp. 61-68.

(2) "Theorie und Praxis der Schwingungsprüfmaschinen" (Theory and Practice of Vibration Testing Machines), by William Späth, Ph.D., Julius Springer, 1934; EMB Translation 51, March 1938.

(3) "Construction and Operation of Losenhausen 440-Pound Vibration Generator," by E.O. Berdahl, TMB Report 539, April 1945.

(4) "Construction and Operation of Taylor Model Basin 5000-Pound Vibration Generator," by E.O. Berdahl, TMB Report 524, April 1944.

(5) "A Vibration Manual for Engineers," by R.T. McGoldrick, TMB RESTRICTED Report R-189, March 1944.

(6) "Mechanical Vibrations," by J.P. Den Hartog, McGraw-Hill Book Company, Second Edition, 1940, p. 52.

(7) "Vibration Tests on USS HAMILTON (DD141) at Washington Navy Yard," by R.T. McGoldrick, EMB Report 372, December 1933.

(8) "A Study of Ship Hull Vibration," by R.T. McGoldrick, EMB RESTRICTED Report 395, February 1935.

(9) TMB letter QS1/S29-7 of 20 July 1944 to Chief of the Bureau of Ships, Design (400).

(10) TMB memorandum S87-19/A11 of 22 June 1943 for file.

(11) "Some Experiments in Stress-Relieving Castings and Welded Structures by Vibration," by R.T. McGoldrick and Capt. H.E. Saunders, USN, Journal of the American Society of Naval Engineers, Vol. 55, No. 4, November 1943.

For convenience, the following prints of the original German plans are on hand in Envelope 216A of the file of the Vibration Section, Structural Mechanics Division:

Plan Number	Title	Date
Losenhausen Pk/341b	Assembly - Plan and Elevations	15 April 1931
Losenhausen Pk/408b	Calculation of Centrifugal Forces	18 August 1931
Losenhausen Pk/409b	Diagram of Centrifugal Forces	18 August 1931
Losenhausen Pk/2046	Locking Levers	20 October 1931
Losenhausen Pk/411b	Electrical Connections	14 January 1932
Losenhausen Ps/14419	Elevation Showing Handcrank Arrangement	16 January 1931
Losenhausen Ps/14438	Gearshift Arrangement	16 March 1931

APPENDIX

DERIVATION OF EXPRESSIONS FOR ECCENTRICITIES AND DRIVING FORCES

It is necessary to derive the eccentricity r in terms of known factors. The only method of changing the unbalance of this machine is to change the eccentricity r of the rotating mass, with respect to the center of rotation.

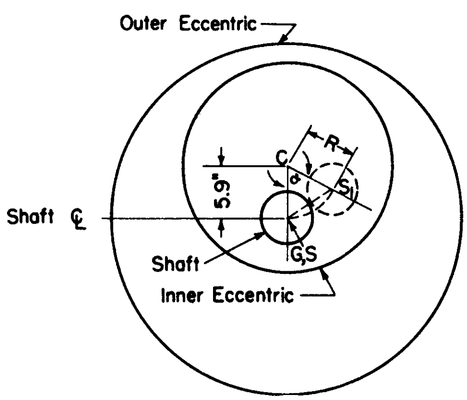

Figure 17 - Diagram of an Eccentric Assembly

The solid shaft outline shows the shaft position at zero eccentricity. The broken shaft outline indicates the shaft position after the inner eccentric has been rotated through an angle of setting α, relative to the outer eccentric.

In Figure 17, C is the center of the inner eccentric, S is the center of the shaft, and G is the center of mass of the eccentric assembly including the shaft end. S and G coincide for the balanced condition. The eccentricity of the inner eccentric with respect to the shaft axis is designated by R. This is also the eccentricity of the outer eccentric with respect to the center of the inner eccentric. The statement that G is the center of gravity of the entire assembly comprising the outer eccentric, the inner eccentric, and the shaft end, is based on the assumption that gear-tooth spaces, locking-block receptacles, and the like, have an insignificant effect upon the position of the center of gravity of this 6000-pound mass. When the inner eccentric is rotated through an angle of setting α from the balanced position, the shaft center moves from S to S_1 in the diagram of Figure 17.

From inspection it is evident that as the eccentricity is changed, the center of mass, G, of the assembly remains fixed in position relative to the periphery of the outer eccentric, but the shaft center S moves away from the center of mass as the angle of eccentricity is increased from zero to 180 degrees. It is obvious that the shaft center S follows a circular path about the center of the inner eccentric C when the inner eccentric is rotated relative to the outer eccentric, and this circle has a fixed radius R which in this machine is 5.90 inches. Since the eccentricity is the distance from the center of mass G to the shaft center S and this is the chord of the arc generated by the shaft center, the eccentricity $r = 2R \sin \frac{\alpha}{2}$, the expression for a length of a chord in terms of the radius of the arc of the chord and the central angle subtended by it. This expression is used to compute the data in Table 1 and the curves of Figure 15.

To set the eccentrics for any given driving force listed in Table 1 on page 21, the angle of setting is selected from the table or from the graphs of Figure 15. The inner eccentric is then turned, while the outer eccentric is locked in place, until the proper angle is obtained.

It must be remembered that the dial on this machine is graduated in index numbers, and that the angle of setting is three times the index setting. The scale itself is nonlinear since it merely indicates the relative rotation between the outer and inner eccentrics, as the outer eccentric rocks about the locking pin during this operation. When the angle α becomes 180 degrees (index setting 60) the full eccentricity of 11.8 inches is obtained.

When a mass is rotating about an axis not passing through its center of gravity, the reaction at the bearings is given by the formula

$$F = m_e r \omega^2$$

where F is the force in pounds,

m_e is the unbalanced mass in pound-seconds^2 per inch,

r is the eccentricity of the unbalanced mass with respect to the center of rotation in inches, and

ω is the angular speed of rotation in radians per second.

The tachometer for this machine indicates the speed of rotation in revolutions per second. The total unbalanced mass is

$$m_e = \frac{2(6000)}{386}$$

Therefore we can write

$$F = kr(\text{CPS})^2$$

where

$$k = m_e(2\pi)^2 = \frac{2(6000)}{386}(4)(3.14)^2 = 1227$$

Therefore

$$F = 1227r(\text{CPS})^2 = K(\text{CPS})^2$$

where

$$K = 1227r$$

and is given in Table 1 on page 21.

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