GENERAL RADIO COMPANY

engineering department

INSTRUMENT NOTES

IN107

September 1965

DYNAMIC BALANCING WITH PORTABLE EQUIPMENT

This article describes a portable balancing setup that makes possible the dynamic balancing of a rotating part in its own bearings and operating under normal conditions. Such on-the-spot balancing is necessary when the rotating part is too large or the production volume too small to permit the installation of balancing machines. Other applications include the rebalancing of parts that have been deformed in shipping, in assembly, or during operation. Portable balancing equipment is also often necessary because of the prohibitive cost of disassembling and shipping the part to be balanced.

The portable balancing setup consists of four parts. A vibration pickup converts the mechanical vibration into an electrical signal, and a variable-frequency filter, or analyzer, is used to select only the frequencies of vibration that are of interest. An amplifier and meter permit the measurement of the amplitude of vibration, and a stroboscope establishes its relative phase.

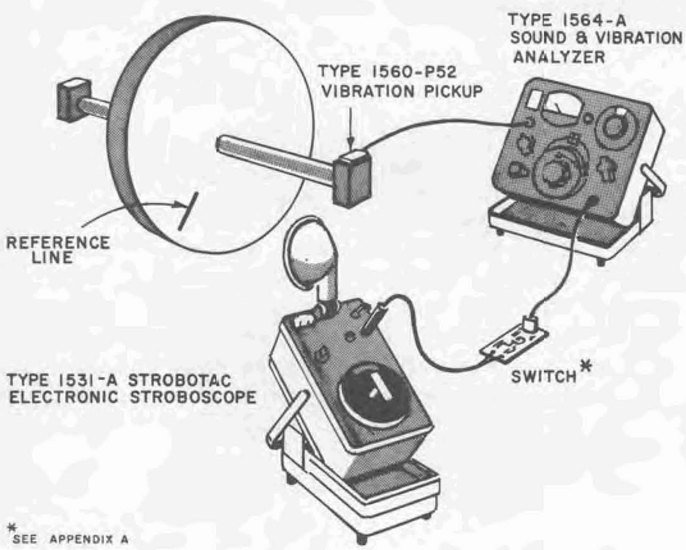


Figure 1. Equipment setup for dynamic balancing.

The recommended equipment interconnection is shown in Figure 1. The vibration pickup, which can be magnetically or mechanically clamped to the bearing housing, provides the input signal to the analyzer. The analyzer filters and measures this signal and provides an output to trigger the stroboscope through a transistor switch. Since a triggering signal is provided, any one of three standard stroboscopes can be used.[1] A transistor switch[2] is connected between the analyzer and the stroboscope to ensure adequate triggering for all signal levels.

The following instructions and example describe in detail the single-plane dynamic balancing procedure, which is usually adequate if the axial length of the rotating part is very small compared with its diameter. Fans and flywheels can often be satisfactorily balanced in a single plane. While it is theoretically possible to perform a static single-plane balance in which an accurate weighting procedure enables gravity to determine the heavy side, it is unlikely that this method would completely eliminate the unbalance. Since even a small unbalance will produce large centrifugal forces at high speeds, it is preferable to balance the part dynamically at the speed at which it will operate.

Objects that have similar axial and radial dimensions require a two-plane dynamic balance. The same equipment described above can be used, but the procedure and the calculations are more complex.

---

[1] The General Radio Type 1531-A Strobotac® electronic stroboscope has an internal oscillator and is calibrated in rpm. Thus it can also be used to measure the speed of the rotating part being balanced. If this information is not required and if a Strobotac is not needed elsewhere in the plant, a lower-cost instrument, the Stroboslave, is adequate. For speeds above 25,000 rpm, or for battery operation (e.g., if no ac power is available), the Type 1538-A Strobotac® electronic stroboscope is used.

[2] Described in Appendix A.

Since both the single-plane and the two-plane balance procedures have been well described,[3] and since the operation of the equipment is similar for both cases, the following instructions and example are given for only the single-plane case.

GENERAL PROCEDURE

The balancing procedure consists of an initial measurement of the amplitude and phase of the unbalance vibration, a second measurement after a trial weight is added to the rotating part, and calculations to determine how that trial weight must be changed in size and location to achieve a balance. (The purpose of adding the trial weight is to obtain the relationship between the unbalance weight and the vibration amplitude and between the position of the weight and the observed phase of the vibration.)[4] The balance thus obtained is not, of course, a perfect balance, but it should be a substantial improvement. If a better balance is desired, the balancing procedure should be repeated, with the instruments set for greater sensitivity and with a smaller trial weight, until the balance is within the prescribed limits.

DETAILED PROCEDURE

If the angular position of the object under test cannot be indicated by its construction or markings, it is necessary to add a mark for use as a phase reference. With the object so marked, and with the equipment connected as shown in Figure 1, the detailed procedure is as follows:

1. Set the analyzer to the 1/3-octave bandwidth and tune the frequency control to the vibration frequency component of interest. If the speed of the rotating part in rpm is known, the frequency dial should be set to this value divided by 60. (The analyzer is calibrated in cycles per second.) If the speed is not known, tune the frequency control until a maximum amplitude is indicated on the meter. The band-level control should always be adjusted for an on-scale meter deflection. The stroboscope should now be flashing once per revolution of the object under test, and the reference line on the rotating part should appear "stopped" by these flashes. If more than one reference line is observed, the frequency control is set at a multiple of the correct frequency, and its setting should be divided by the number of reference lines that appear.

2. Record the amplitude indicated on the meter and note the orientation of the "stopped" reference line on the rotating part. On polar graph paper plot a vector $\bar{A}$ with the same orientation as the reference line and with a length proportional to the vibration level measured.

For example, if the analyzer measures 30 millivolts and the reference line has an orientation of 60° above right-side horizontal, the vector $\bar{A}$ should be plotted to scale as shown in Figure 2.

3. The object under test is stopped, and a trial weight is added. Familiarity with the mechanical system being tested will in time permit the selection of a trial weight about right for the system and the measured vibration level. Until this familiarity is achieved, the trial weight must be selected at random, and the balancing procedure may have to be repeated a few times to reduce the vibration to within the specified limits.

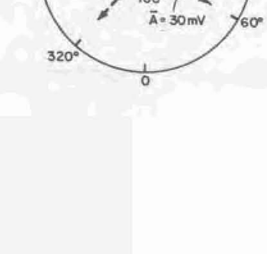
4. When the object under test is rotating again, the only adjustment that should be made on the analyzer is to change the band-level control, if necessary, to obtain an on-scale meter deflection. The new amplitude is recorded, and the new orientation of the reference line is observed.

5. A new vector $\bar{B}$ is plotted with a length corresponding to the new amplitude as shown in Figure 3. The angle at which vector $\bar{B}$ should be drawn is *not*, however, the angle at which the reference line on the rotating part was observed in step 4. Vector $\bar{B}$ is drawn on the side opposite from vector $\bar{A}$, maintaining the same angle with respect to vector $\bar{A}$. In the example, a weight of one ounce is added, the new level measured is 25 millivolts, and the reference line is observed "stopped" at 320° (=-40°). Vector $\bar{B}$ is plotted to scale at an angle of 160°. $[60° - (-40°)] = 100°$ and $60° + 100° = 160°$.

6. Since the original measurement gave the vibration caused by the original unbalance, and the

Figure 2.

Figure 3.



[3] Thearle, E. R., "Dynamic Balancing of Rotating Machinery in the Field," *ASME Transactions*, Vol 56, 1934. Paper AMP-56-19.
MacDuff & Curreri, *Vibration Control*, McGraw-Hill Book Co., Inc., New York, 1958, pp 150-156.

[4] If an absolute measurement of the unbalance vibration is required, the vibration pickup and the analyzer should first be calibrated with a vibration calibrator.

second measurement gave the vibration caused by the original unbalance *plus* the trial weight, it is now possible to determine the vibration caused *only* by the trial weight. A vector $\overline{C}$ is drawn on the graph paper from the end of vector $\overline{A}$ to the end of vector $\overline{B}$, as shown in Figure 4. This vector $\overline{C}$ is the difference between $\overline{A}$ and $\overline{B}$ and represents the vibration due *only* to the trial weight. In other words, if the same trial weight had been added to a perfectly balanced part, the vector $\overline{C}$ would have been proportional to the unbalance vibration caused.

7. The length of vector $\overline{C}$ may now be either measured on the graph paper or computed.[5] In the example, the measured vector $\overline{C}$ corresponds to a vibration level of 42 millivolts.

8. The original unbalance, represented by vector $\overline{A}$, can be canceled only by an equal unbalance on the opposite side, Since this whole procedure assumes that the vibration levels measured are proportional to the amount of unbalance causing the vibration, the levels plotted as vectors $\overline{A}$ and $\overline{C}$ are thus proportional to the original and trial unbalances, respectively. To reduce the trial vibration level represented by vector $\overline{C}$ to equal the original vibration level represented by vector $\overline{A}$, one must reduce the trial weight by the ratio of the lengths of vectors $\overline{A}$ and $\overline{C}$. Referring to Figure 5 in the example, the one-ounce trial weight must be reduced by the ratio of vector $\overline{A}$ (30 mV) to vector $\overline{C}$ (42 mV). The balance weight needed is therefore: (1 oz) (30 mV/ 42 mV) = 0.71 oz.

[5] Calculations are shown in Appendix B.

9. To cancel the unbalance, the balance weight must be located directly opposite it. Again referring to Figure 5, one can see that the position for the balance weight must be an angle (b) counter-clockwise from the position of the trial weight. Angle (b) may be measured or computed.[5] In the example, angle (b) is 36°. The final balance weight of 0.71 oz should thus be positioned 36° counter-clockwise from the position of the trial weight. If a final measurement shows that the vibration is still greater than desired, the balancing procedure may then be repeated.

—R. E. Anderson

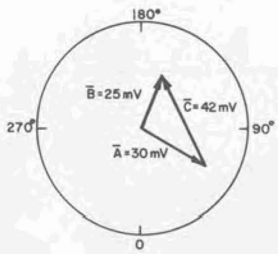


Figure 4.

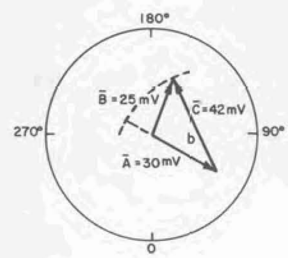


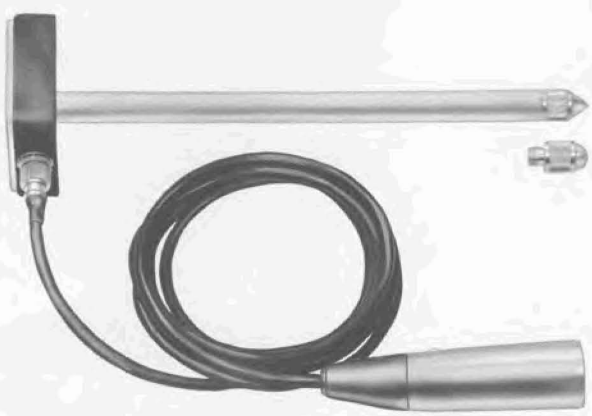
Figure 5.

APPENDIX A

The following list includes a brief description of the necessary equipment and alternate instruments that may be desired in special areas.

GENERAL RADIO TYPE 1560-P52 VIBRATION PICKUP

A transducer with a nominal sensitivity of 75 mV/g, this pickup has a frequency range of 2 to 2000 c/s (120 to 120,000 rpm), and an acceleration range of 0.1 to 39,000 in/s².



GENERAL RADIO TYPE 1564-A SOUND AND VIBRATION ANALYZER

A tuned voltmeter with bandwidths of 1/3 and 1/10 octave, this battery-operated analyzer has a frequency range of 2.5 to 25,000 c/s (150 to 1,500,000 rpm) and a voltage range of 0.3 millivolt to 30 volts.

GENERAL RADIO TYPE 1531-A STROBOTAC® ELECTRONIC STROBOSCOPE

A source of extremely short-duration, bright, white-light flashes that cause a rotating object to appear "stopped" when rotating at the same rate as the flashing, this stroboscope has an internal oscillator that covers a range of 110 rpm to 25,000 rpm with 1% accuracy. It can also be triggered by an external signal (such as the signal from the analyzer) to flash in synchronism with that signal.

TRANSISTOR SWITCHING CIRCUIT

To provide adequate triggering of the stroboscope at low signal levels from the analyzer, the following transistor switching circuit should be used. The necessary components can be purchased at any radio- or electronics-parts supply house for less than $1.50, and only a few minutes are required to assemble them.

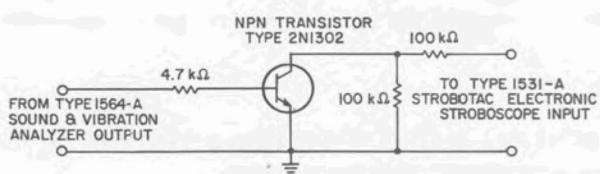


Figure 6. Transistor switching circuit for use with Type 1531-A Strobotac® electronic stroboscope.

GENERAL RADIO TYPE 1560-P54 HIGH SENSITIVITY VIBRATION PICKUP

This pickup with a nominal sensitivity of 600 mV/g can be substituted for the Type 1560-P52 Vibration Pickup if greater sensitivity is desired. The frequency range is 20 to 2500 c/s, and acceleration range is 0.01 to 3900 in/s^2.

GENERAL RADIO TYPE 1539-A STROBOSLAVE

This low-cost slave stroboscope can be used as an auxiliary source of stroboscopic light, triggered by a Strobotac. The specifications are similar to those of the Strobotac, but an external triggering signal is required, since there is no built-in oscillator.

GENERAL RADIO TYPE 1538-A STROBOTAC® ELECTRONIC STROBOSCOPE

This high-speed stroboscope can be substituted for the Type 1531-A if a range of 110 to 150,000 rpm is desired. The Type 1538-A will be required when the balancing system is to be completely battery-operated. The Type 1538-P3 Battery and Charger will then also be required. This unit uses the same transistor switching circuit as the Stroboslave.

APPENDIX B

The following calculations can be used in the balancing procedure to determine the length of vector C, the angle (b), and the final balance weight. The calculations refer to Figure 7 and the example used in the text.

$$/\overline{C}/ = \sqrt{A^2 + B^2 - 2AB\cos(c)} \qquad \sin(b) = \left[\frac{\overline{B}}{\overline{C}}\right]\sin(c)$$

Measured: A = 30 mV; B = 25 mV; (c) = 100°

thus: cos (c) = (-0.17) sin (c) = 0.98

$$C = \sqrt{900 + 625 - (2)(30)(25)(-0.17)}$$

C = 42 mV.

$$\sin(b) = \frac{25}{42}(0.98) = 0.58$$

(b) = 36°

FINAL BALANCE WEIGHT: $(1\ \text{oz})(\frac{A}{C}) = (1)(\frac{30}{42}) = 0.71$ oz.

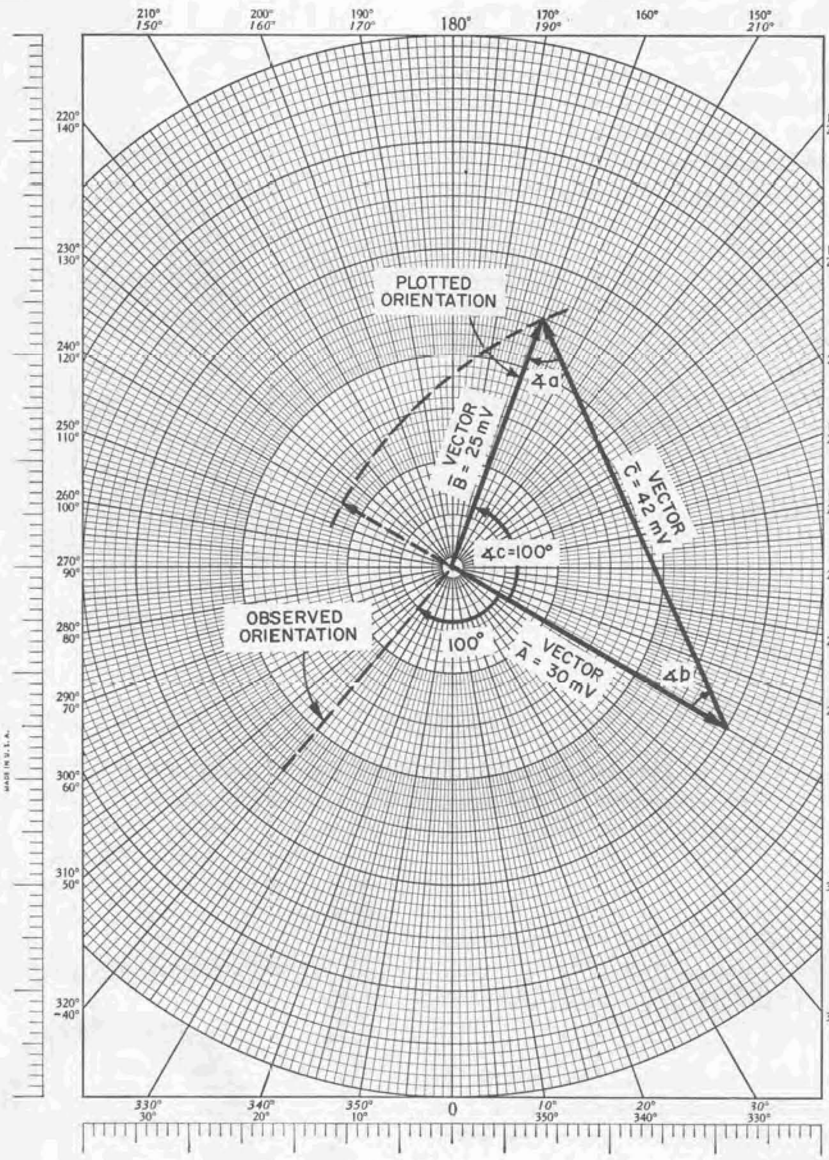


Figure 7. Vectorial representation of text problem.