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LIFE TESTING OF MECHANICAL INSTRUMENTS

With increasing large scale production of common measuring instruments, such as pressure gages, thermometers, ammeters, voltmeters and watt-hour meters, coupled with extensive use of such devices in connection with millions of automobiles, household utensils, and the like, in everyday use, — the matter of studying the life of such instruments and other more specialized sorts, becomes a matter of first importance. To double the life of an instrument made by the million annually, may be the means of saving capital charges and maintenance and field inspection costs enough to equip and man a considerable laboratory. Such testing frequently develops unexpected means of protecting an instrument from the effects of wear or abuse or of improving its service accuracy.

2 The purpose of life testing is obviously to predetermine, usually in the shortest practicable space of time, the character of service the device under investigation will afford after a stated period of actual use, and the probable extent of its useful life under the actual conditions of use, such conditions of use being approximated, so far as feasible, by setting up an average or normal manner of operation or "loading" or a representative extreme condition, depending upon whether the test is to determine the normal or minimum service life and performance. In the former case, the instrument may have to meet a requirement that under all specified conditions of service, an average service life of a certain period must be attained, while in the latter case, it may be required that under the most severe conditions of use or the most severe combination of such conditions, falling within the limits permitted by the specifications as to service, none of the instru-

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ments shall fail. Failure may be defined to suit the requirements of the particular case in question, as complete effective cessation of the intended functions of the device, or quality of performance of the intended function falling without certain established limits of accuracy or sensitivity. For example, in the case of a stroke or revolution counter, failure may be determined as the point of life at which coördinated advance of the counting units definitely ceases (and such failure can normally be detected by simple observation) while in the case of a pressure gage, the indication of pressure, to be of value, must be at all times maintained within certain more or less restricted limits of accuracy. Naturally, the more complex the functions of the device, the more difficult it will be to set up testing conditions which rationally and correctly represent in a demonstrable manner, either average or extreme conditions of service.

**SELECTION OF SPECIMENS FOR TEST**

3 The proper selection of the instrument for test is most important; samples submitted by a manufacturer especially for examination are likely to be far from representative of the regular product, even though there is no definite intention to make a special selection of such samples. In general, it may be said that the cost of life testing of apparatus is high enough to warrant the purchase of test specimens on the open market, or their selection by a purchaser by random choice from the makers' stock shelves.

4 Nevertheless, even if samples known with certainty to be representative are not available, life testing may be proceeded with with reasonable assurance of developing valuable information, for the life test is pretty sure to bring to light hidden weaknesses and defects and to develop, by comparison with other instruments, points in which a given instrument is definitely superior.

**PREPARATION FOR TEST**

5 The test should be started with the instrument clean, and lubricated in about the manner that may be expected to characterize the regular stock of instruments of the same type at the time of their being put into service. It is practically impossible except in the case of continuously lubricated apparatus, and such are rare in the field of measuring instruments, to provide during a life test, lubrication of the same characteristics as that typifying service life. In the case of such an instrument as a time switch,
or a telephone calling dial, re-oiling in service may be specified, to be done at definite time intervals, say once every two years. In such cases, of course, re-oiling during life test would be done at intervals of operation equivalent to the number of operations expected to occur over the interval between oilings in normal use. For various reasons, this is only a coarse approximation to the desired result, since lubrication is affected by time, as well as by use, owing to drainage, oxidation, and probably also to an appreciable extent, to evaporation. Moreover, in rapid operation, the oil may be momentarily exhausted at a given bearing point and wear then proceed at a rapid rate, whereas in actual service, the long time intervening between some successive operations, may permit replenishment of the oil on the bare surfaces, by slow flow from neighboring oily areas.

6 There are a number of other respects in which an accelerated life test fails by a significant factor to approximate normal service, among which may be mentioned the effects of corrosion due to atmospheric exposure, complicated in many cases, as in the chemical industries, by the presence of corrosive gases and vapors in the air, or by high humidity; deposition of dust or gritty particles from the air, or from neighboring tools or machinery; fading or obliteration of graduations due to light or moisture; and what is perhaps most important practically, the abrasive and hence wearing effects of particles removed from rubbing surfaces, during operation. The deposition and distribution of these particles will be much different during accelerated test than in normal use, and it is a fact established beyond question that such abrasive particles affect the wear life of an instrument or small machine by a large factor. A case is in mind where the life of a simple contact-making device comprising a metallic brush rubbing on alternate segments of conducting and insulating material, was multiplied by perhaps five, by the simple expedient of dusting off the worn particles of metal from the brush and disc as fast as they appeared. In this case the abraded particles determined the wear; in others it may be the air-borne particles shed by near-by machinery or tools.

7 In general this points a very useful lesson, well supported in the writer's experience: that in any instrument in which the prevention of wear, and lengthening of service life are important, regular cleaning is essential; and more important still is the protection of the working parts, from air-borne dust particles, by use
of an airtight case, or one so designed, by the equivalent of baffling or otherwise, as to slow down the air stream entering the case so much as to occasion the dropping of the dust particles before the slow-moving air stream has reached the working parts.

8. Apart from the wearing out of working parts of the instrument occasioned by the entrance of dust, the errors of indication produced by increases of and changes in the friction are likely to increase to an important degree the need for and cost of recalibration. Instruments having a hinged door or cover should be so designed that the dust dislodged when the door is opened, does not fall inside the case. Apart from the cost of cleaning an instrument, better results are obtained if the dust is prevented from ever entering the working parts, as is well recognized in the care used in constructing watch and chronometer cases as nearly dust tight as possible.

9. The effect of dust on the wear of an instrument is so significant that it is to be recommended that in important cases, an attempt be made to approximate during the accelerated test the average dust deposition that may be expected to occur during normal use of the instrument.

**DESIGN OF THE TESTING DEVICE**

10. The test should be so carried out that abnormal deterioration of the instrument due to excessively high stresses, as those of impact, developed as a result of fast operation, can be avoided as far as possible. In this matter, as in those discussed above, it is to be remembered that an accelerated test can never correctly simulate service, but that a great deal can be done to eliminate obvious errors. For example, in life-testing of a pressure gage, the pressure can be applied quickly enough without introducing the impact effect of water hammer, even if a liquid medium is used for applying the pressure. Similarly in cam-operated mechanical testing devices, the design of a cam can easily be made to approximate the continuously varying acceleration of harmonic motion, in the absence of specific information regarding the nature of the acceleration to which the apparatus is subjected in use.

11. In some cases, as in automobile, locomotive, and airplane instruments, the definite introduction of vibration treatment of the instrument during test will be justified. As to the simulation of such vibratory service by artificial means, few data are available
to guide. A study of this subject in relation to airplane instruments, and of the effect of the shocks of transportation on the accuracy of aneroid barometers, was made at the Bureau of Standards before and during the war, under the direction of Professor M. J. C. Hersey; it is doubtful if there is any other experience in this field available for reference, although it is quite certain from experience with automobile clocks and locomotive pressure gages, that the impact stresses of such service greatly accelerate the wearing out of the instrument.

12 The establishment of the highest possible speed of operation of the instrument within the limit of reasonable simulation of service use is often a matter of importance, as in the case of some devices whose useful life is required to run into millions of operations; and in such circumstances the expenditure of considerable care and study in the refinement of the testing apparatus will well repay the effort in the time and supervision saved on the test, and the more prompt availability of results.

13 Another point regarding the details of the design of the testing machine relates to the difficulty already discussed, of rapid wearing out of instruments due to abraded metallic particles. There is great danger that unless special precautions are taken against it, the testing machine itself will contribute largely to the supply of such particles, and care is to be taken to protect the instruments under test by suitable screens and guards at all points at which they are subjected to bombardment of material including lubricating oil, discharged from the parts of the testing machine.

14 In the case of instruments which have a very long life, running into millions of operations, it will be impossible probably to design the testing machine so that it will outlive in every detail the instruments tested, and in such cases care should be given to devising the details of the machine for easy replacement at a minimum cost, often at the expense of compactness, and neatness of appearance.

MAINTENANCE DURING TEST

15 It is often impossible on account of the excessive cost involved, to test enough instruments of a given type to afford a true statistical picture of the performance of the type; and in but few cases would so exhaustive an examination be warranted. Fortunately, the differences between commercial instruments are of
a large enough order that normally no means of fine discrimination are required.

16 Thus, it is often desirable, as soon as a part breaks or a serious defect or error develops, to repair the fault and restore the instrument to test, due care being taken to record the stage of operating life at which each such failure takes place. A careful examination of the whole instrument should be made and noted at such times in order that the relation of the defect to others already or subsequently developing, may be determined in reviewing the data at the completion of the test, as it often happens that the occurrence of one type of failure will influence the appearance of another.

17 As has already been indicated, cleaning and re-oiling at proper intervals during the life test will need to be carried out, in most cases, and the record should include a statement as to the means of cleaning, whether wiping, brushing, blowing out, or washing with a solvent; and of the kind and amount of lubricant used.

CALIBRATION DURING AND AFTER TEST

18 The ordinary type of calibration will not be of great service in this sort of investigation, except with instruments of relatively low variance. Hysteresis or cyclic calibration conducted under the régime laid down in the several papers on this topic will aid definitely, however, in showing up important differences in amount of wear, failure of lubrication, etc. For a fuller discussion of this point see the three articles listed below, wherein the subject of friction and backlash in their relation to instrument errors are discussed in detail, and it is shown that the hysteresis or load-deflection loop of an indicating instrument operated aperiodically over a definite range, after cyclicization, and in the absence of external vibration, affords a powerful means of discriminating between types and individuals. In the wear test, these methods are of especial value, because they disclose the net effective result of the wearing action, integrating as it were the wear damage of all the journals, bearings, pivots, gears, rollers, cams, etc., involved in

the linkwork, as well as all resulting changes in frictional resistances, whether due to change in the finish of surfaces, exhaustion of lubricant, or interposition of dust particles. Means are readily developed for applying the same or equivalent technique to integrating or value-controlling instruments. The hysteresis determination will afford a better index of the state of the instrument before, during and after a given wear life than the other available means of estimation such as calipering and weighing of journal and bearing parts; this because the cyclic calibration method automatically and necessarily weights each component of wear in proportion to its proper part in determining the inaccuracy and variance of the indications of the instrument.

19 Of course, the cyclic calibration need not be carried through in the presence of such massive and perhaps fatal defects, as breakage of parts, marked sticking or jamming of joints, or significant derangement of important adjustments.

20 Other means of interpreting wear damage are familiar, as calipering of holes and journals, and weighing of parts that have relative motion, to determine the amount of material removed. The clearance of a journal in its bearing can be conveniently determined by observation with a low-power measuring microscope, or more simply by moving one part back and forth in relation to the other while the plunger tip of a dial micrometer is kept in contact with the moving element. The amount of clearance can be readily estimated from the maximum amplitude of the indicating hand of the gage. The depth of shallow pits, or depressed thrust areas can be measured by a depth-measuring microscope.

THE NATURE OF MECHANICAL WEAR

21 A very important and suggestive study of the wear of metals which run together is found in a paper by L. Jannin and L. Guillet. (Rev. de Met. 19, pp. 109–116, and pp. 117–119, Feb. 1922.) These investigators found, under the conditions of their experiment, which permitted ready measurement of the worn surface, that the principal cause of wear in bearings is insufficient polish on the rubbing surface of the journal, while the chief cause of the wear on the journal is impurity in the lubricating oil. The latter condition, no doubt, will result from impurities introduced in the form of dust or gases by exposure to the atmosphere or by imperfect cleaning of the bearing parts at the time of manufacture. The best results as to endurance of the bearing were obtained not
when the surfaces were of materials of maximum dissimilarity, but when both consisted of a cemented and quenched case-hardening steel.

22 It is probable that instead of a minimum of wear being determined by dissimilarity merely, of surfaces, fineness of grain in both surfaces might produce the same result. Perhaps the maximum wear occurs when the maximum projection of particles transverse to the direction of rubbing exists, so that when a particle is torn out by abrasion, its uprooting leaves the surface again relatively rough.

23 When a small particle is uprooted by the abrasive action in the bearing, it leaves the smoothness and mode of frictional engagement of the surrounding surfaces relatively unchanged; when, with coarse structure a large particle is uprooted, its removal results in increased wear for a time, due to the shift of the directions of the particular elementary reactions between the wearing surfaces, and the exposure of new, hitherto protected, particles to the wearing action.

LIMITATIONS AND SPECIAL FEATURES OF THE FORCED TEST

24 It seems likely that even under the best conditions, the forced test cannot be applied without making due allowance, in the interpretation of results, for the specific points in which such tests cannot quite represent service conditions. In some cases the forced test is less severe than service, especially, for example, in cases where the movements in the instrument are mainly elastic rather than mechanical; but usually the forced test is rather more severe than the normal service. Nevertheless, due to the fact that some commercial instruments fall far short of normal requirements or differ so widely in a given type that discrimination is easy, the forced test is destined to play a more and more important rôle in instrument investigation and control. Certain it is that if makers of cheap watches were to have subjected samples to life tests under moderate jolting, at a balance vibration period artificially adjusted to say one-fifth the normal running value, many serious defects which characterize these watches would have been corrected before they were so widely marketed. Similarly, certain indicating and recording thermometers and pressure gages are subject to a very serious and troublesome shift of the zero due to uncoiling of the Bourdon tube easily brought to light by life test conditions.

25 It is to be noted that in a good many cases, the life test
of an instrument may be made self-recording, or self-limiting, so that failure to register correctly may either be made to stop the test, or to register itself in some easily interpreted way. For example, as described in outline in the paper by the writer in Management Engineering, June, 1922, a considerable number of recording thermometers, or pressure gages may be simultaneously life-tested in such a manner that the occurrence of important discrepancies can be directly noted on the record chart, by comparison with a reiterated standard temperature or pressure. Similarly, recording voltmeters and ammeters may be made to write their own life history by actuation through proper regulating resistances from an interrupted source of constant potential. Many electrical instruments, speed-governing devices and the like may be subjected to constant automatic supervision by connection to voltage release or time-interval relays. Pressure regulators may be "supervised" by a recording pressure gage.

CONCLUSIONS

26 The forced test method of studying a product, whether looking toward improvement, re-design, or competitive quantity purchases, is an important technique, especially meriting intensive development in the field of measuring instruments, where new methods may be successfully generalized, in most cases, to a wide range of types of apparatus. This method of test can go far in eliminating the uncertain and always debatable experience factor in instrument design, and will ultimately place design for production upon the same stable basis as design for research. Development of improvements and new devices will not then have to await the slow trying out of performance in service, with the unreliable and conflicting types of information which field observations normally imply, and the fact that such information does not commonly reach the people whose decisions control design. It is easy to ascribe failures in the field to abnormal conditions or abuse; in laboratory tests the conditions, even though they can never precisely represent service, can be standardized and controlled with certainty and flexibility. In the matter of dust-tightness, for example, such differences as may appear in ordinary inspection of installed instruments are too easily ascribed to accidental differences in severity of exposure as affected by air currents, fineness of dust particles and other factors that are highly variable under service conditions.