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Maintainability of electronic instruments for meteorological applications

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सार — हालांकि इलैक्ट्रानिक उपकरणों की अनुरक्षणीयता (एम) सिद्धांत का उद्‌भव हाल में ही हुआ है किंतु यह उन मौसम विज्ञान उपकरणों पर अनुप्रयोग के लिए महत्वपूर्ण है जिनकी विशेष अपेक्षाएं हैं। मरम्मत हेतु 'एम' को मात्रात्मक माध्य समय के रूप में परिभाषित किया गया है और यह उपकरण के असफल होने को प्रकृति से प्रभावित है। उपकरण विभिन्न अवस्थाओं, टीथिंग समस्या, उपयोगी जीवन तथा अन्तिम कला से होकर गुजरता है। अभिकल्प और उत्पादन अवस्था में बहुत सी अनुरक्षणीयता समाविष्ट की जा सकती है। यह उपकरण की समय अवधि के दौरान उसकी समग्र लागत को कम करता है। मौसम विज्ञान उपकरणों के लिए विशेष अनुरक्षण सहायता प्रणाली आवश्यक है। अंकीय प्रणाली की समस्याओं को दूर करने के लिए हाल के ही कुछ यंत्रों पर विचार किया गया है।

ABSTRACT. The concept of Maintainability (M) of electronic instruments, though of recent origin, has important application for meteorological equipments, which have special requirements. M is defined quantitatively in terms of mean time to repair and is influenced by the failure behaviour of an equipment. An equipment goes through teething trouble, useful life and terminal phase. Much of maintainability can be incorporated during design and production phase. This reduces the effective overall cost of the equipment during its life time. Special maintenance support system is necessary for meteorological instruments. Some recent tools for trouble shooting in digital systems have been discussed.

1. Introduction

Breath-taking developments in Electronics and Space Science in the recent decades have penetrated the meteorological field also in the form of wide spread usage of sophisticated electronics in observation, dissemination and processing of weather data. Processing and dissemination are largely based on computers and telecommunication equipments which have extensive usage in numerous other fields as common means of data processing and transmission. The observational equipments are, however, designed rather for a narrow and special purpose, *viz.*, for application to meteorological measurements. Thus the amount of attention, care and research effort that could be applied in a cost effective manner to the design, manufacture and deployment of equipments like computers cannot be expected in the case of specialised meteorological instruments even though the latter has definitely benefitted from the technological developments in the former area. The equipments have become more reliable, versatile and superior in performance. However, increasing sophistication of meteorological instruments has brought in its wake some attendant problems like difficulty of field maintenance, greater skill needed for operators and technicians etc. Meteorological instruments, in fact, have special requirement in terms of maintainability. These are often deployed in harsh field conditions with little *in situ* maintenance facility, operated by people who may not have adequate training or background and are normally used in an operational environment with rigid internationally orchestrated time schedule for completion of a task. Since meteorological data is handled from the stage of observation to that of processing in accordance with the international standards of accuracy, methods etc set by the World Meteorological Organisation, the equipment performance has to be maintained at an acceptable level all the time so that the data is compatible internationally. Viewed largely from hardware angle, the special requirement of electronic meteorological instruments could be listed as follows :

(a) Satisfactory performance in different climatic conditions and heights.

(b) Robust in design and construction so that it can be easily handled in the field and can withstand rough handling.

(c) Easy to maintain.

(d) High degree of reliability so that need for maintenance action is minimum.

(e) Operation and maintenance need not require high level of training or expertise.

(f) Need for spares inventory and test equipment should be minimum.

The question of Maintainability of meteorological instruments becomes important in this context. Though maintainability as a distinct discipline was developed some years ago primarily by scientists in the military sector, there does not appear to have been any scientific attempt to apply this concept in relation to meteorological electronic equipment. The purpose of this paper is to present certain maintainability aspects of electronic equipments keeping in view the special requirement for their meteorological applications.

2. Maintenance and maintainability

As is well known, maintenance of an equipment is the process of ensuring its functional performance at the specified level of excellence either through advance action or after the fault has occurred. It thus ensures long life and overcomes temporary system deterioration including failures that result from usage, normal life, storage, environment etc. While Preventive Maintenance (PM) takes advance action to prevent deterioration of the equipment, corrective maintenance restores the equipment to its original performance level after the deterioration has set in or failure has occurred. Naturally preventive maintenance is more desirable as it prevents or delays development of faults. However, with increasing usage of long life solid state devices often with diagnostic facilities and with good quality passive components, the importance of PM has rather diminished in case of modern electronic equipments.

An important attribute of any electronic equipment is its maintainability, which is a measure of the ease or facility with which the equipment can be maintained. Maintainability has the following components :

(a) Inherent Maintainability (IM),

(b) Operational Maintainability (OM).

Inherent maintainability is built into the system during its design and manufacturing stage. Proper choice of components, sufficient design redundancy, wide dynamic range of parts and overall behaviour, proper mechanical structure, component layout, provision of test points with signal details and safety factors contribute to designed maintainability. Choice of material and tools, workmanship, manufacturing technique, quality control, supervision and preparation of elaborate maintenance manual determines the maintainability that can be incorporated during manufacturing stage. Once the equipment has come into use, its maintainability will be influenced by the nature and environment of its usage. Storage and installation environment, transportation mode, quality of operators and maintenance personnel, spares inventory and availability of test instruments are some of the factors that will determine the maintainability while in operation. Once the equipment reaches the user, very little can be done to improve IM though feed-back from users can be incorporated in future models. However, OM can be greatly improved by proper management of maintenance organisation. We shall discuss these aspects at some length in a later section.

In order to quantify maintainability, it can be treated as the probability that an instrument can be restored to its useful operation condition in accordance with specified functional limits within a given time constraint when maintenance action is carried out according to prescribed procedures and resources. Let us define Mean Time (T_r) To Repair (MTTR) an equipment as:

$$T_r = \frac{\sum_{k=1}^{k} N_k \lambda_k t_k}{\sum_{k=1}^{k} N_k \lambda_k}$$

where, N = Number of similar components of the k-th type in the equipment,

λ = Failure rate of these components,

t = Corrective repair time, and

k = Number of different types of components used.

here, T_r is the ratio between total down time and total number of repair actions completed. It is thus the mean of all repair actions over a sufficiently long time. In actual practice, MTTR can be found out by identifying a circuit component (*e. g.*, local oscillator unit or a resistor), observing its failure rate over a long time and then finding out its average maintenance task time taking into account time involved in different subtasks like logistics, fault localisation, access to faulty component, repair or replacement of the component and system realignment.

Another important maintenance parameter, *viz.*, Mean Time Between Failures (MTBF) can be defined for the device in a manner similar to MTTR. Since, the total time is made up of MTBF and MTTR, the ratio between MTBF and total time gives a measure of operational availability of a device. Assuming that failures occur at random, it can be shown that maintainability, M is related to Mean Time To Repair by the following exponential relationship (Nageswara Rao 1980):

$$M = 1 - e^{-t/T_r}$$

where, t is the permissible repair time. Obviously $(1-M)$ will indicate the probability of not completing maintenance action within the given time constraint. Maintainability (M), defined in this manner, is thus dependent on the permissible repair time, *i.e.*, operational consideration and is not fully an absolute attribute of the equipment itself. Permissible repair time is decided by the operational requirement. Main synoptic hours, which occur every 6 hours, alongwith the complexity of the equipment, will have an important bearing on repair time constraint for meteorological observational equipments so that minimum number of observations are missed. For a cyclone detection radar or a radio theodolite it could be 6 hours and for a storm detection radar 3 hours. On the other hand a Close Circuit Television (CCTV) system used for transmitting current weather reports to Air Traffic Control Units has to be repaired, say, within two hours of failure as alternative arrangement for delivery of half hourly meteorological reports may not be able to sustain for long.

3. Failure characteristics

The failure rate of an equipment increases in an exponential manner with the number of components used. In the initial period of its life many of the design and manufacturing deficiencies manifest themselves in rapid

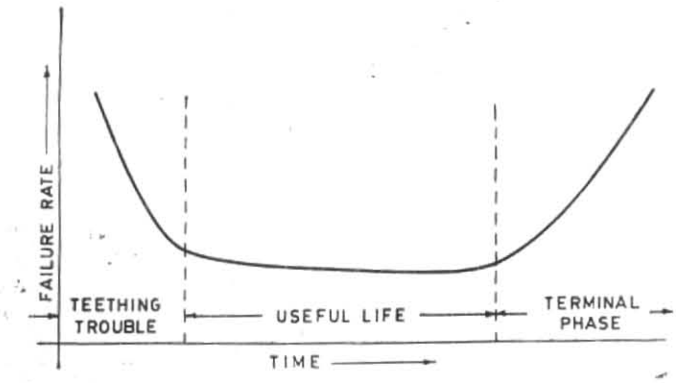

Fig. 1. Life of history of an equipment

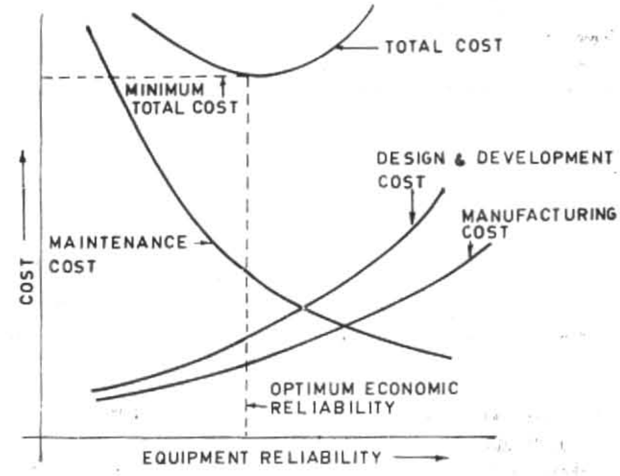

Fig. 2. Reliability — Cost trade off

succession particularly when the equipment faces real-life operating condition. The rate of fault occurrence during this period of teething trouble is initially very high and is normally covered by guaranteed maintenance by the manufacturers. The rate falls off rapidly to reach a level of steady performance (Fig. 1) after some time. Such steady failure rate continues for a long time and marks the useful period of its life. With the wear and tear increasing with usage, the failure curve again shows an upswing indicating end-of-life of the equipment. Failures themselves occur at random and closely follow Poisson's distribution during most of the life of the equipment.

4. Maintainability and equipment cost

It is often not realised that maintenance cost forms an invisible component of the equipment cost. Greater the value of M, lower is the cost of maintenance. On the other hand, greater investment in development, design and manufacture is necessary to increase M. This is schematically shown in Fig. 2. The total cost is the aggregate of all these costs (Kalla and Dhillons 1980). Therefore, an optimum economic point can be worked out from this total cost to get the minimum cost of the equipment though consideration of greater reliability may over-ride the cost factor in certain applications. For example, for an X-band storm detection radar which has to work almost continuously over the thunderstorm season, greater availability of equipment and greater probability of its successful operation are more important than its minimum cost.

5. Designing for maintainability

As mentioned earlier, IM, an integral part of M, is built into the equipment in its design and production stage itself. In an equipment designed and built with good maintainability, it will not only reduce its down time but will also absorb much of the expertise requirement of maintenance personnel and need for maintaining a large inventory of spares as failures will be few and far between. There is indeed great scope for improvement of IM through the incorporation of certain features for ease of maintenance while in use. Standardisation and interchangeability are important in design. The components and sub-units should be standardised to the maximum extent with easy accessibility to components and sub-units. Modular design of sub-units and minimising the range and diversity of the components in different sections are helpful in maintaining the equipment. As far as possible, standard circuit blocks should be used for standard functions wherever feasible. Design tolerance should be wide enough to accommodate slight deviation of in electrical and mechanical specifications of the replacement parts from the original one. Proper identification of components and sub-units should be provided. Appropriate safety measure for the equipment and personnel is to be built into the system itself. Good testability and serviceability have to be built into the system in the design phase itself. Test points with proper location for operational ease alongwith their signal characteristics are essential for easy diagnostics. Cables with proper identity and without sharp bends are helpful. The connectors should be of quick disconnect variety with spare pins available. All adjustment points should be easily accessible. Idealy, there should be built-in redundancy so that in the event of failure of one sub-unit or components, it should be possible to keep the device operating even if in a degraded mode by alternative arrangement. In fact, this is one of the techniques applied to many devices where there is no scope for further *in situ* maintenance, *e. g.*, missiles, space-craft etc. Use of special grade and over-rated components particularly in critical paths where redundancy is not practicable would improve operational reliability of the equipment. Different plugs should be such that one sub-unit does not get fitted into the place of another by mistake. Provision of indicating meters or lights helps in monitoring equipment performance and quick diagnosis of faults. On the mechanical side heavy items like transformers should be located at the bottom rack. Provision of suitable equipment lifting means, drawers on roll-out slides, hinged panels with extended cables, adequate ventilation and shock absorbers etc are part of good engineering practice. Appropriate packaging of components influence the degree of maintainability. Meteorological equipments have to be specially designed for suitable environment. In India they should be capable of working in condition ranging from sub-zero temperature to more than 50°C in the sun, near zero to 100% humidity, clear to dusty air and sea level to the Himalayas.

6. Maintainability during use

It is imperative to have a very detailed manual for quick repair. Calibration requirements and maintenance procedures should be clearly spelt out and personnel appropriately trained. Judicious inventory of spares and test equipments in terms of variety, number and location is essential for quick restoration of the health of the equipment. In a country of India's size, regionalisation of spares and maintenance personnel is essential for less sophisticated equipments which are large in number and widely dispersed, *e.g.*, radiosonde, disaster warning system. In fact this has already been done. However, for complex systems like large computers, *in situ* availability of maintenance infrastructure is essential. In general, first line maintenance capability has to be established in the field observatories in order to attain greater levels of equipment availability. Storage, mobility and transportation conditions are important factors that have to be carefully considered.

As mentioned earlier, Preventive Maintenance (PM) improves the availability of the equipment. PM has to be worked out only after carefully observing the failure rates of different components and should aim at complete regeneration of the equipment. However, PM may be imperfact due to less than adequate skill of the maintenance personnel, inferior replacement parts, imperfectness of adjustments and reassembly and other operational factors. For imperfect PM action, the system reliability can be maximised by proper choice of the PM intervals (Chaudhuri and Sahu 1977).

7. Digital and microprocessor-based equipment and PCBs

Presently microprocessors and other complex solid state devices are being used extensively for meteorological applications. Printed Circuit Boards (PCBs) with microprocessors, ROMs, RAMs and other integrated devices present a considerable challenge to maintenance personnel and need special arrangements for maintenance. Printed circuit boards in general can basically be, (*i*) Digital with bus oriented multifamily types, *e. g.*, microprocessors, ROMs, RAMs and single family type with LSI, VLSI, (*ii*) Analog for high frequency or low frequency use (OP Amps. R.F. components, L,C,R, etc), and (*iii*) Hybrid combining both digital and analog (ADC, DAC, comparators). The so-called "digital screw-drivers" comprising Logic Probe, Logic Pulser, Logic Clip and Current Tracer are normally adequate for random logic systems. They prove to be rather ineffective when microprocessors are involved. Normally one has to use what may be described as "data domain test instruments" like Logic State Analyser and Logic Timing Analyser that are now widely used as test equipments for ensuring satisfactory maintainability of microprocessor-based instruments. While the former is more useful for software problems, the latter is largely used for hardware faults. However, more advanced devices like Digital Signature Analysers are now available largely through the pioneering effort of M/s Hewlett Packard ,Company USA (Chain 1977, Frohwest 1977). Logic analysers, though very useful in the design stage, are less useful in field maintenance as they are very expensive and need highly trained personnel to interpret the test results. The signature analysers are capable of data compressing and inducing circuit generated stimulus. A test stimulus is allowed to reside in the ROM that excites various nodes of the system under test and produces a complex stream of digital bits carrying the signatures of the defective sub-units. Each bit stream is compressed into an easily recognisable number. If a faulty signature is encountered at a particular node this can easily lead to the detection of the defective components. The prerequisite for the successful use of signal analyser is that the instrument under test should be designed so as to perform the same operation during the analyser time window in order to ensure repeatable results. Generally the test programme is so devised as to activate the maximum number of components and nodes in the circuit. The digital signature analysers have proved to be eminently suitable for field servicing and self test features of digital circuits.

8. Conclusion

We have discussed the concept of maintainability keeping in view the special requirements of meteorological electronic equipment. In view of specialised and limited demand for such equipments, it may not always be possible to induce the manufactures to incorporate many of the desirable features into the design and production of the equipment. However, if maintainability demonstration is made a part of the purchase specification, it is likely to improve inherent maintainability of the equipment. Since electronic equipments suffer technological obsolescence at a fierce rate because of the rapid progress of science in this field, it is essential that a high degree of maintainability is assured when a meteorological system is inducted into service. "Throw away" philosophy in maintenance is impractical in India, particularly for imported equipments. It is thus essential that proper maintenance support is built by assuring trained personnel, adequate spares and test equipments, and organising them at different levels in terms of both geographical locations and expertise available at different points.

References

Chain, A.Y., 1977, "Easy to Use Signature Analyser Accurately Trouble Shoots Complex Logic Circuits, "H.P. Journal, May 1977, pp. 9-14.

Chaudhuri, D. and Sahu, K.C., 1977, "Preventive Maintenance Interval for Optimal Reliability of a Deteriorating System," IEEE Trans. on Reliability, Vol. R-26, December 1977, pp. 371-372.

Frohwest, R.A., 1977, "Signature Analysis : A new Digital Field Servicing Method", H.P. Journal, May 1977, pp. 1-8.

Kalla, S.K. and Dhillons, G.S., 1980, "Reliability Maintainability and Availability of Fire Control Radar Equipments," MELEC-80 (Technical Group EME), B-3.

Nageswara Rao, K., 1980, "Maintainability of Electronic Systems for Military Applications," MELEC-80 (Technical Group EME), A-7.