CONDITION BASED MAINTENANCE

. . . .How to get started. . . .

by

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1.0 . . . . ABSTRACT

This paper offers a "step-by-step" method which may be used to implement a condition based maintenance (CBM) program. Based on an aggregate of experience from industrial and utility companies around the world, the methods presented here are, for the most part, field tested. Previous papers presented in this series have focused on definitions and concepts. This instalment is aimed directly at **how**.

The acceptance of CBM concepts has been slow in the United States. Other countries, New Zealand is used in this paper as an example, are farther along in the reformation of their utility industries. This fact, coupled with their smaller geographic size, has led to a faster acceptance of CBM concepts. While stopping short of wholesale application of CBM, some U.S. and many international power systems asset owners are implementing CBM and finding it to be a cost effective approach to maintenance practices.

This paper presents a compilation of the implementation procedures used by several power systems. Starting with equipment oriented Predictive Maintenance (PDM) the paper moves on to the more comprehensive and cost effective concepts of CBM. Along the way we will compare and contrast on-line monitoring versus off-line test procedures, we will discuss how the various CBM procedures work on different types of equipment, and — finally — we will present the step-by-step approach that should allow the asset owner to optimize the investment placed into a maintenance program.

2.0 . . . . PREDICTIVE MAINTENANCE

Concepts

Most modern maintenance programs are, at least, starting with predictive maintenance concepts at their base. Predictive maintenance comprises methods which attempt to “predict” or diagnose problems in a piece of equipment based on test results. Predictions are usually based on the trending of results. Consider the following simple example:

An insulation test is performed on a 15 kV substation bus. The one (1) minute test result, corrected for temperature, is 5,225 MS. Referral to International Electrical Testing Association (NETA) standards shows that a minimum value of 5,000 MS is acceptable. Your initial evaluation might be to accept the equipment and then go on. Reviewing Figure 1, however, will undoubtedly lead you to a totally different conclusion.

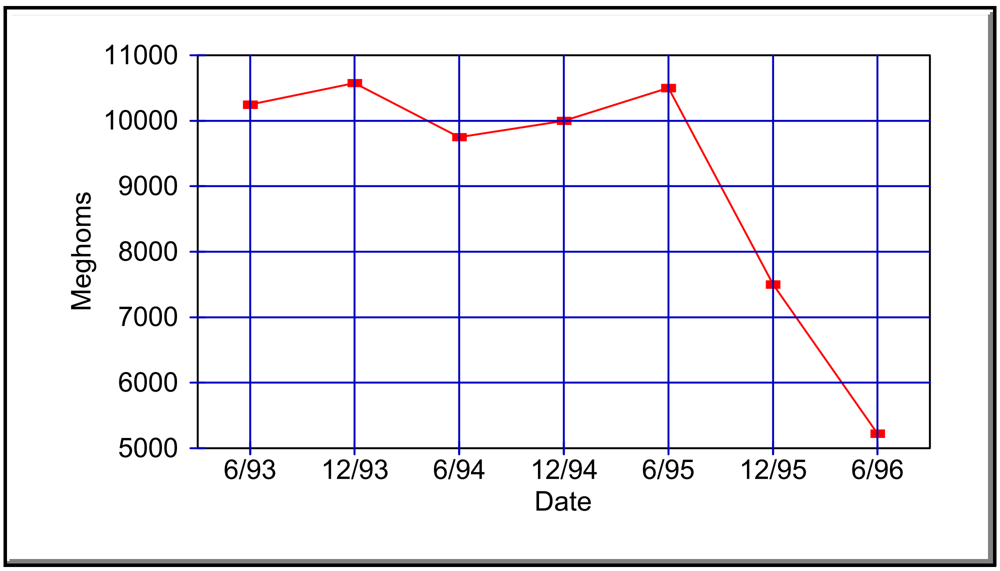

Figure 1 - Insulation Resistance Trending Chart

Figure 1 clearly shows a seriously deteriorating piece of equipment. The last two readings, taken six months apart, show a drop from approximately 10,500 Megohms to 5,225 Megohms. Clearly, this equipment is failing. Assuming this trend continues, the insulation resistance of this equipment will reach zero in one year.

This example, while simple, clearly establishes the value of trending and, by extension, the value of applying predictive techniques to test results. Later, this example will be extrapolated to show the power of even more sophisticated evaluation methods.

On-line vs. Off-line

Since the early 1990s, major interest in so-called “on-line” monitoring has started to appear in the industry. The concept, quite correctly, is based on the belief that if equipment can be evaluated, and yet still remain in service, the overall cost of maintenance will go down. Consider the previous example. In order to make the insulation resistance measurements, the gear had to be taken off-line. This means that during the maintenance interval it is non-productive. If, in some way, the condition of the equipment could be evaluated while still in service, great savings would be realized.

On-line monitoring of this type makes enormous sense in many situations for many kinds of equipment. Generators, for example, can be readily monitored based on a number of available parameters, including the following:

< Stator voltage, current, and phase angle
< Exciter current and voltage
< Temperatures
< Cooling gas density
< Bearing Vibration
< Lubricating oil condition

Other electrical equipment such as circuit breakers, relays, and switchgear are not as readily assessable using on-line techniques. Through diagnostic oil tests, transformers may be evaluated while on-line; however, a complete transformer evaluation would be need to involve off-line parameters such as insulation resistance, insulation power factor, and/or polarization index readings.

Ultimately, the decision to use on-line measurements, off-line measurements, or both will be based on an overall evaluation of economics and system availability.

3.0 . . . . CONDITION BASED MAINTENANCE

CBM adds two enormously important dimensions to classical predictive maintenance. First, CBM deals with the entire system as an entity. This holistic approach to maintenance represents a major shift from the piecemeal methodologies of the past. While CBM can still be implemented “one step at a time,” it realizes its greatest potential when applied consistently and evenly across the entire range of system maintenance concepts.

The second added dimension is the concept of ignoring or extending maintenance intervals. PDM trending techniques have been used historically to confirm maintenance decisions that would previously have been based on expert opinions. While this approach may often find problems not otherwise identifiable, as in Figure 1 for example, it does little toward reducing the cost of classical preventive maintenance programs. In fact, because of the additional analysis required, PDM may actually increase day-to-day costs slightly for some installations.

CBM on the other hand, because of its systemic approach, usually decreases long term maintenance costs. Consider Figure 2 for example. After all of the various criteria are entered into the CBM model, and the analysis is performed, the results can cause the maintenance interval to be decreased, maintained or increased. In other words there is an actual possibility that maintenance costs will go down based on an increased time interval between shutdowns.

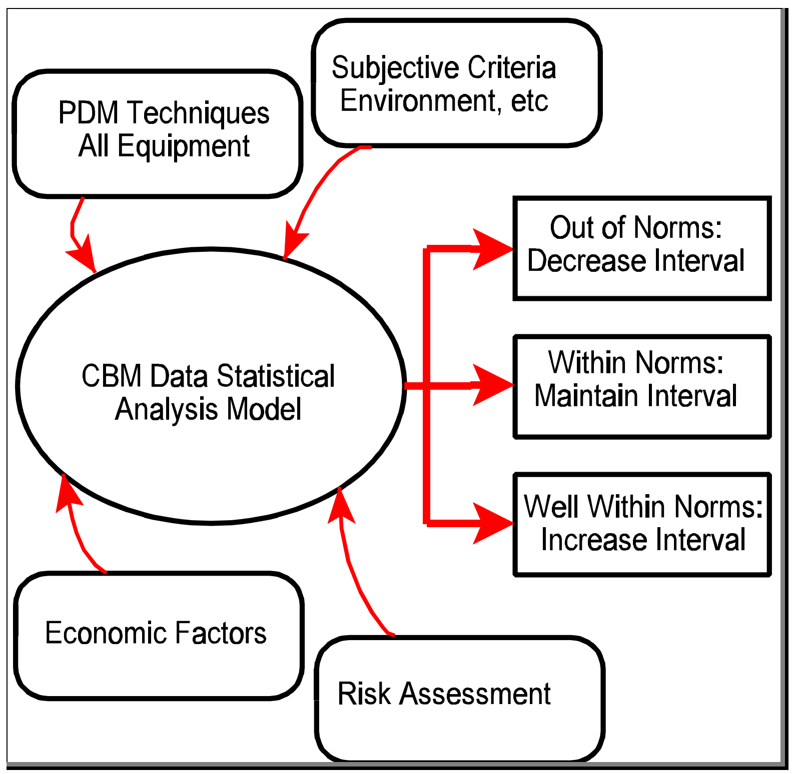

Figure 2 - CBM Flow Chart Model

4.0 . . . . GETTING STARTED — PHASE 1

One of the very attractive aspects of CBM is the fact that it can be implemented in a relatively inexpensive, step-by-step approach. Because CBM is based on the equipment oriented concepts of PDM,

Table 1 – Safety program review elements

Safety equipment	—	proper selection, testing up-to-date, readily available
Safety procedures	—	in compliance with current national and local standards
Safety training	—	all personnel thoroughly trained and familiar with all applicable safety standards – OSHA compliance the **minimum** standard
Safety documents	—	up-to-date and in compliance

it can be applied gradually — one system at a time. Eventually the entire power system is included in the program and cost savings begin to multiply.

Safety Procedure Review

Any major change in system maintenance or operations should include a thorough review of safety procedures. At a minimum, the following should be considered:

A complete treatise of safety program review and setup is beyond the scope of this paper; however, the reader should refer to the latest revisions of CFR Title 29 Parts 1910.269 and 1910.331 - 1910.335.

Data Collection and Storage Procedures

Maintenance data and its uses are among the key differences between classical and modern maintenance methods. In the past, maintenance results from any given interval were reviewed and filed. Little, if any, attention was paid to comparison or trending.

As previously described in this paper, trending and statistical analysis are the fundamental building blocks of CBM. Comparing data absolute values, and perhaps more importantly, comparing data deviations via statistical analysis provide information never before available. Obviously, a statistically relevant database is required.

Maintenance management software (MMS) has been available for many years. Such software may vary slightly from one manufacturer to another, but the basic purpose and design are similar from one package to another. Fundamental equipment information is stored — usually in a detailed manner. Information such as size, date of purchase, ratings, cost, maintenance cycle, and equipment specific notes are all maintained. Most MMS packages will even print out work orders when calendar based preventive maintenance schedules dictate. Few, if any, of these packages will store maintenance results, and none will perform the trending or statistical analysis required for full implementation of PDM or CBM.

Fortunately, many power system operators (whether industrial or utility) have kept good paper records over the years. Relay, transformer, circuit breaker, switchgear, and rotating equipment maintenance test sheets are usually kept for several years in paper form. Converting these records to a computerized database is time consuming, but simple.

Table 2 – Master equipment database

Field #	Field Name	Description
1	Equipment	Relay, transformer
2	Manufacturer	ABB, GEC, Schweitzer
3	Model	CO-9, DH150 . . .
4	Test type #1	Pickup, PI, PF . . .
5	Test type #2	Timing, PD, DGA
6	etc.	etc.

The platform chosen for the record keeping system should be one of the commercially available personal computer relational database programs. Some companies opt for a spreadsheet program; however, I recommend against this. Most spreadsheet programs are long on computations power and short on database manipulation abilities. Since database files (tables) will readily import into a spreadsheet for analysis, use the database.

The table structure should be as general as possible, and it should be done in two, linked database files. This allows for a variety of types of equipment as well as future modifications. Table 2 lists the type of information and suggested field names for the master database, and Table 3 shows the test result database.

Note that each field in the results database is linked to the appropriate test field in the master database. Notice also that each test result record is dated to allow identifying the specific test interval. This structure is flexible and is supported by virtually all of the commercially available PC database programs.

Table 4 – Test results database

Field #	Linked to	Result	Comments
1	4	2	Dimensions of result depend on specific test
2	5	4.5%	
3	6	1	
4	etc		

This relatively simple structure allows access to the data for analysis and review. For easiest results, an user interface may be programmed to allow simple data entry. If required, a "bridge" program may be written which will allow data to be transferred from automated testing programs such as PulseMaster or from automatic testing equipment such as computerized power factor test sets.

Table 3 – Key items for preliminary plan

- Equipment to be maintained
- Tests to be performed
- Dates of implementation
- Budget items and magnitudes
- Expected results
  - Short term
  - Medium term
  - Long term
- Evaluation and modification program

Equipment failure and outage information

To help with the risk assessment portions of the CBM program, a compilation of outage data needs to be compiled. This information can include such items as type of outage, cause, length, cost (estimated if necessary), date, and other such data. For power systems with relatively little outage data a manual listing is probably adequate; however, computerizing (using the same database as the test results data) is recommended.

Outage information may be used to prioritize the implementation sequence of the CBM program. Obviously, equipment with a high failure record and/or a high value to the operation, should be enrolled in the program first.

Equipment database

The equipment database will be developed in parallel with the other databases. If desired, the equipment database may be linked to the master maintenance database (Table 2). It may also be incorporated in the master maintenance database; however, more flexibility is realized if they are kept separate.

Preliminary budget and plan

The final step for phase 1 is the establishment of a preliminary plan and a budget. The preliminary plan should include the steps shown in Table 4.

Emphasize that this plan is preliminary. You should expect changes as the actual program implementation begins. For example, some equipment, such as low and medium voltage circuit breakers, are not as readily predicted as other such as transformers. Because of this, you may decide to drop detailed statistical analysis in favor of a less rigorous approach.

5.0 . . . . GETTING STARTED — PHASE 2

Now it is time to begin in earnest. The information garnered in Phase 1 will be put to work as a living, active Condition Based Maintenance Program.

Develop detailed evaluation criteria and methods

Based on the test result data gathered in Phase 1, the development of control chart strategies[1], and/or other statistical evaluation techniques should be begun. The exact nature of which strategies should be used may not be immediately apparent. Two options are available as shown in Table 5.

Table 5 – Evaluation criteria options

1.	Contract with a CBM consultant for statistical criteria implementation.
2.	Start simple. Use graphical trending in a spreadsheet.

Contracting with a qualified CBM consultant who can assist you in the selection and implementation of appropriate strategies. Starting simple with a commercially available spreadsheet may not be as rigorous or technically satisfying as more sophisticated statistical analysis, it may well provide a satisfactory compromise between competing technical and economic factors.

Finalize recommended maintenance procedures and intervals

This is one area that is very easy to overkill. Remember that maintenance procedures can be added as needed in future intervals. Using transformers as an example, Table 6 lists typical, predictive result types of tests that might be used. Notice also that the so-called subjective criteria that are included. The opinions and observations of skilled technicians along with the ambient environmental conditions are extremely important in the overall evaluation.

[1] Condition Based Maintenance, Cadick, Manker, DiLeo . . . . AVO Tech Conference, 1995

Table 6 – Transformer PDM tests

- ! Oil screening tests
  - " Dielectric strength
  - " Interfacial tension
  - " Acidity
  - " Moisture
- ! Gas-in-oil diagnostic tests
- ! Insulation power factor
- ! Polarization index
- ! Temperature
- ! General condition (1 - 10 scale)
- ! Environment (1 - 10 scale)

Test reporting forms and/or software

Test forms have been around for as long as electrical equipment. Virtually ever test technician has, at one time or another, created his/her own form. Two basic approaches are now available — Printed paper forms and direct computer entry.

Printed paper forms

Such forms are available from a number of sources.[2] The major limitations of preprinted forms is the need for modification and manual transfer of data into the various computer databases described previously.

Direct computer entry

If a user-friendly interface for the database has been designed, a mini-version may be taken into the field by the maintenance technicians. After each test, the technician can keyboard the results directly into the computer. The information can then be electronically downloaded into the main maintenance PC either via diskette or via a company local area network.

As another option, if the necessary translation software is available, the test results may be loaded directly into the computer from the test equipment. This approach is especially effective when the test is actually performed under computer control. Commercially available "bridge" software is being developed in many parts of the industry to allow such transfers.

[2] See NFPA 70B — Recommended Practice for Electrical Equipment Maintenance

6.0 . . . . SUMMARY

Rising costs, reduced budgets, competitive market structures, complex equipment, employee attrition — all of these factors have added to the complexity and difficulty of successfully completing the electrical maintenance mission. Previous papers in this series have discussed the philosophies and concepts of modern maintenance techniques such as PDM and CBM.

Implementation of CBM has been delayed in many companies by the perception that it is expensive, difficult, or both. In this paper, we have shown that CBM is, in fact, not difficult to implement. Nor need it be initially expensive. A measured, methodical development plan can allow the modern power system maintenance team to implement and quickly realize the ultimate values of Condition Based Maintenance.

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