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THE EFFICIENCY OF VIBRATION MONITORING SYSTEMS

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INTRODUCTION

The use of vibration analysis to monitor the condition of vital rotating machinery has become more and more widespread over the last 15 years and is now common practice in many plants. This is particularly so where continuously operating machinery is used, e.g. in the processing and power industry. There are essentially three main aims for these activities:

- o Increase plant availability:
  - Avoid unscheduled shut-downs by giving early warning of impending failure
  - Give early indication of incipient malfunctioning to allow for planning of necessary repairs, thereby minimizing down-time and disruption of production
- o Reduce maintenance costs:
  - Detect malfunctioning at an early stage before secondary damage is caused
  - Prolong intervals between inspection and overhaul on the basis of vibration monitoring
  - Maintain a good state of balance and alignment of shafts and bearings to reduce the rate of wear and fatigue
- o Improve plant safety:
  - Reduce the risk of components being run to break-down (fire, leakage, missiles)

To what extent can then these aims be fulfilled by a vibration monitoring programme and what is the balance of costs between installation and operation of monitoring equipment on the one hand and expected gains in terms of improved availability and reduced maintenance costs on the other? Further, will not the possible occurrence of unjustified alarms from such a system off-set the gains? Questions like these are at the bottom of decision-making, when the installation of vibration monitoring equipment is considered. One cannot expect answers in absolute terms, but some published experience from monitoring programmes will be briefly summarized below.

Dutch Shell [1] have studied the correlation between bearing vibration levels and component availability for approximately 100 pumps of different types and sizes in petrochemical plants. Above a threshold level of bearing vibration (≈ 5 mm/s peak) availability decreases linearly with increased vibration (0.11 % decrease per mm/s increase). Though the scatter obviously is large, the trend is clearly discernible. According to an investigation by Acoustic Ltd [2] concerning two petro-chemical plants, the volume of repair diminished by 25 % after the introduction of a vibration monitoring programme at the one plant, while a multifold reduction of severe break-downs was reported at the other plant. In a report from the US Naval Ship Engineering Center and MTI [3] between 20 % and 30 % of all unplanned shut-downs of gas-turbines could be traced to excessive vibration levels as the fundamental cause. In the literature there are several case histories described where impending catastrophic failures have been avoided at the last moment through vibration monitoring. Three recent examples concerning very large turbo-generators can be mentioned: one 1 000 MW set in the US (Cumberland), [5], one 660 MW set in the UK (Drax), [4], and one 630 MW set in Scandinavia, [5].

PLANNING A COST EFFECTIVE MONITORING PROGRAMME

There are several national and international standards in existence, which specify how vibration measurements should be carried out, what signal analysis should be made and what levels should be considered "good, satisfactory, unsatisfactory or unacceptable". These standards are based on long experience of vibration monitoring and give a starting point for most monitoring activities. It is inevitable, however, that such standards become very general in their approach without taking due consideration to the individual characteristics of machines of different types and sizes. It is therefore the author's belief that the key to efficient monitoring lies in tailoring instrumentation, signal processing, alarm levels and trend analysis carefully to the object being monitored. The first step in such an analysis would be to rank the rotating components involved in the process chain under consideration according to the need of monitoring for each individual machine. Criteria for setting up these priorities could be e.g.:

- The importance of each component for the total process (continuous, intermittent or stand-by operation, existence of redundance)
- The value of the produce
- The value of the component itself
- Safety aspects
- The history of repairs or break-downs for each component

A list of priorities of rotating components of the Nuclear PWR Ringhals 2 was set up by Hunyadi, Sunnersjö, Fasth, [5], according to these criteria. The list was based on interviews with operational and maintenance personnel, literature studies and consideration of component design, see Fig. 1.

GROUP A			GROUP B			GROUP C			GROUP D		
451. GENERATOR	313. REACTOR COOLANT LOOPS	321. RESIDUAL HEAT REMOVAL		334. BORIC ACID	322. CONTAINMENT SPRAY	711. COMPONENT COOLING	414. CONDENSATE	414. CONDENSATE DRAINAGE	415. PREHEATER, DRAINAGE	342. LIQUID WASTE PROCESSING	343. GASEOUS WASTE PROCESSING
	412. TURBINE	334. CHARGING		415. MAIN FEEDWATER	426. AUXILIARY FEEDWATER	532. ROD CONTROL	416. AUXILIARY FEEDWATER	435. GENERATOR COOLING	741. CONTAINMENT VENTILATION	413. CONDENSER VACUUM	415. SEAL WATER
								445. MAIN COOLING WATER	751. AIR COMPRESSOR		443. STARTUP PUMPS
								715. SALT WATER COOLING			

Fig.1. Components arranged in order of priority

The next step in planning the monitoring programme for the whole process would then be to tailor a specific programme for each individual component. The logical sequence when setting up these programmes would be to investigate and define the following items in the order: Fault types - characteristic vibrations - measurement and analysis needs - alarm functions. A schematic example of such a causal chain is given in Fig. 2. An exhaustive inventory along these lines was made in [5] for the components in Fig. 1. It is not possible to enter into the details here, but merely to summarize the result. Hence for group A individual monitoring programmes based on automatic digital analysis were worked out, for group B periodical manual monitoring programmes were suggested, while for group C periodical monitoring according to ISO 2372 was recommended. Components in group D were left unmonitored with a few exceptions.

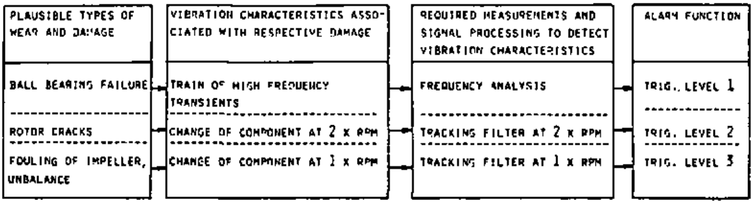

Fig.2. Schematic monitoring programme for centrifugal pump (syst. 321)

EVALUATING THE EFFICIENCY OF A CHOSEN MONITORING METHOD

It is by no means self-evident what is implied by the efficiency of a certain monitoring method. Clearly the user of a monitoring system wants his system to trigger (give indication of malfunctioning) when, and only then, a fault in the monitored machinery has occurred. This means that the monitoring method used must be selective in its operation.

The output of the vibration analysis system that triggers the alarm could be termed the monitoring parameter (MP), and thus the machine is considered faulty when MP exceeds a preset threshold level (TL). The following discussion will be concerned with the correct choice of MP and TL. As an example the characteristic pedestal vibrations generated by roller bearings with spalling fatigue and surface roughness (abrasive wear) will be compared with vibrations of the same bearings when new. A few different analysis methods designed to detect these faults were tried by Sunnersjö [6] and the discussion is based on these results. The selectivity (S) of respective methods could be defined as the ratio between MP_{new} and $MP_{damaged}$, see Table 1.

Table 1. Selectivity based on experiments, [6]

No	Type of damage	Choice of MP	S
1	spalling fatigue	MP = RMS for 10 - 5 000 Hz	1.2
2		Autocorrelation. MP = height of peak at $\tau = 1/f_{rp}$ where f_{rp} is roller passage frequency	2.9
3		MP = counts of transients exceeding a threshold level	2.7
4		Frequency analysis. MP = mean height of peaks at 5th to 15th harmonic of f_{rp}	2.3
5	surface roughness (abrasive wear)	MP = RMS for 10 - 5 000 Hz	1.4
6		MP = RMS for 2 500 - 5 000 Hz	3.6
7		Auto-correlation. MP = time lag until stable autocorr. function	2.3

The S-values listed represent the outcome of the respective methods for a particular application, but do not say anything of the merits of these methods in a general sense.

Although the S-value as illustrated above is a useful starting point-it is however a rather blunt instrument. For a bearing, either new or with specific damage, the MP-value will vary with e.g. speed, power, load, temperature and so on. If MP-values are known for a realistic range of load conditions it might in some cases be possible to take the analysis a step further. In a certain monitoring situation four conditions of machine and alarm system are possible:

Table 2

	Machine	Monitoring system	Probability
1	No fault	Alarm	P_1
2		No indication	P_2
3	Malfunction	Alarm	P_3
4		No indication	P_4

To simplify matters, assume that the monitored machine is originally fault-free and after a sufficient length of operating-time malfunction will always develop. The monitoring situation could then be represented by the simultaneous monitoring of two identical machines, one fault-free (A) and one faulty (B). One possible definition of monitoring efficiency would then be the probability of events 2 and 3 taking place simultaneously. Since events in machine A are statistically independent of events in machine B, the monitoring efficiency would then be

$$M_{eff} = P_2 \cdot P_3 = (1 - P_1) \cdot P_3 \qquad (1)$$

Obviously M_{eff} will be a function of TL. Thus, except for giving an indication of the effectiveness of a certain vibration monitoring method on a specific application, the M_{eff}-function also provides a means of finding the optimal TL-value. Using an example from [6], the P_1- and P_3-functions are plotted in Fig. 3 for monitoring based on methods 1 and 2 of table 1. Using Fig. 3 and eq. (1) the M_{eff}-functions can

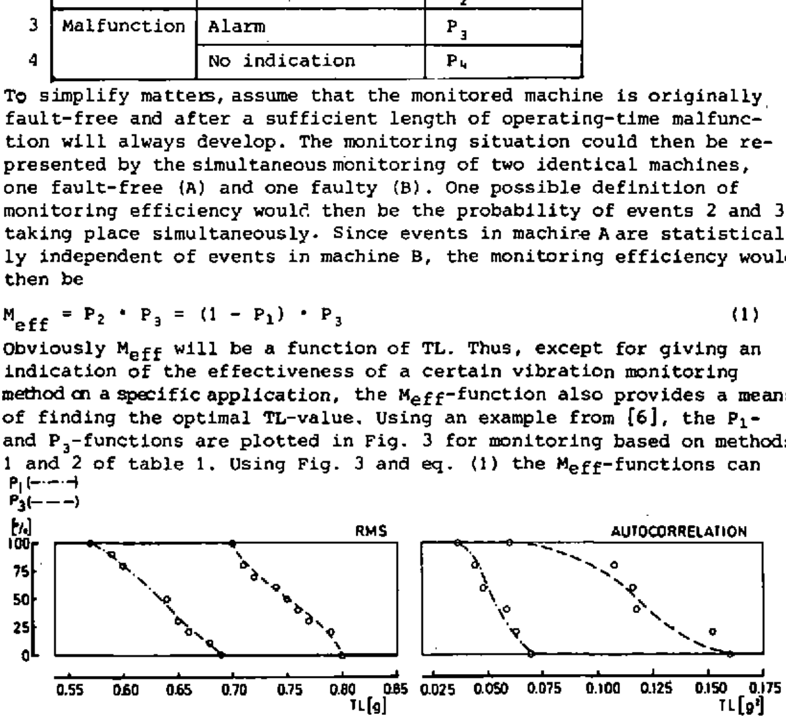

Fig.3. New roller bearing (P_1) and with spalling fatigue (P_3)

then be plotted as in Fig. 4, with normalized TL-values on the x-axis. The value 100 then corresponds to the optimal TL-value, i.e. the TL-values giving M_{eff} maximum for the respective methods. In a practical situation the P_1- and P_3-functions will often not be well-known, particularly at a new application with no experimental feed-back available. Another important requirement is thus the stability of the monitoring process, i.e. that the TL-value can be chosen with a wide enough margin without causing a strong decrease of monitoring efficiency. This property could be described by the quantity W, marked in Fig. 4, which directly shows that M_{eff} is 80 % if the TL-value is chosen within ± 3.6 % from optimum for RMS monitoring and within ± 26% from optimum for autocorrelation monitoring. The latter method thus seems more reliable from a practical point of view.

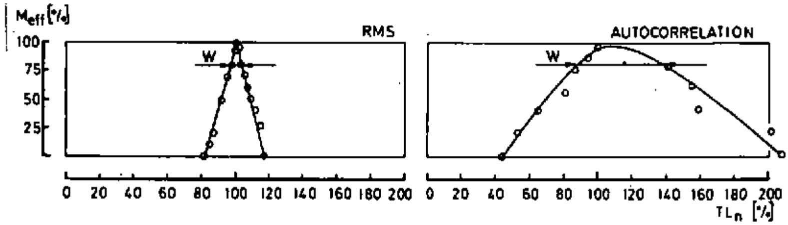

Fig.4. TL_n = 100 corresponds to 0.69 g and 0.070 g^2 resp.

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