FLEET EXPERIENCE WITH VA TECHNIQUES

BY

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The Fleet Vibration Analysis Unit (FVAU)

This unit was set up as part of the engineering staff of the Commander-in-Chief Fleet and started survey work in August 1974. The unit is still an integral part of the C.-in-C. Fleet's organization and is complemented for one lieutenant in charge, one fleet chief MEA or fleet chief mechanician, three chief artificers or chief mechanicians, and six first class artificers or mechanicians. The headquarters is at Portsmouth and a sub-unit has recently been formed at Devonport comprising the fleet chief and two of the first class ratings. The officer-in-charge has overall responsibility for planning, reporting findings, and recommending action. The unit is concerned only with the surface fleet; the Submarine Command and the Fleet Air Arm use vibration analysis but have developed separately.

Training

FVAU personnel initially attend a one-week basic course at H.M.S. *Sultan*. Continuation training is given within the unit where new members work with more experienced men until they are competent to work independently. The instrument manufacturers provide two-day courses in advanced analysis and advanced balancing techniques for equipment users. Benefit is derived from these courses by meeting and exchanging views and experience with representatives of a large cross-section of industry also active in the vibration analysis field as well as from formal training.

Types of Survey

The terms of reference for the unit are contained in Fleet Engineering Order 0305 which tasks the unit with carrying out pre- and post-refit surveys of all machinery in destroyers and frigates and also special surveys when requested. Pre-refit surveys are conducted three to four months before start date and the report is used to assist in making out the refit work package. In this context, good reports are as valuable as those showing problems. The survey covers all major items and, for a frigate, takes ten man-days. Comprehensive post-refit surveys, covering the same machinery, provide a base-line signature of the machinery and this is used for comparison in future survey analyses. Post refit, the aim is to check items as soon as they have been set to work; thus, not only is base-line information obtained as early as possible but also defective or badly installed machinery can be corrected before completion date with little or no penalty. The existing routine surveys, hitherto planned to occur at six-monthly intervals between major surveys, are being phased out as ships adopt condition-based maintenance (with the installation of the Maintenance Management System (MMS)—DCI 190/80) and carry out their own vibration monitoring.

The unit also conducts special surveys of machinery at the ship's request, either to help in the diagnosis of defects or to give confidence after repair.

Although the number of pre-refit and post-refit surveys varies little from year to year, the number of special surveys has increased significantly as the technique has become more widely used. In 1976, 45 ships were visited and 1848 machines were surveyed. In 1980, these figures had increased to 329 and 4172 respectively, and remedial action was recommended on 499 machines.

Feedback from the fleet plays a most valuable part in the unit's work. It is important to know whether an analysis has proved correct or incorrect as, without this, future improvement in the unit's results cannot be expected.

Various sources of information are taken into account when analysing a vibration signature: these include the particular machine's previous vibration signature and mechanical history, the signatures of other similar machines, the vibration severity chart produced by the instrument manufacturer, and the historical record of previous similar recommendations, the latter being particularly important in preventing a repetition of incorrect diagnosis.

Success Rate

Diagnosis of defects is not always correct. From the feedback received this year, however, the unit's diagnosis has proved to be correct in 88 per cent. of the cases. The success rate depends on many factors, the chief of these being familiarity with the machine or machine type. Incorrect diagnoses tend to occur most frequently in new classes of ships and is rare in ships for whom a great deal of data is held. For instance, Type 12 and LEANDER Class frigates are fairly simple for the diagnosticians despite the preponderance of gear-driven, variable-speed machinery. On the other hand, the first survey in an ISLAND Class patrol vessel and, more recently, a survey in H.M.S. *Speedy* proved quite difficult. H.M.S. *Invincible*'s base-line survey was not particularly difficult as most of the machinery is constant speed and directly driven.

Survey Reports

The survey reports include the vibration analysis data sheets and analysis and recommendation sheets. The aim is to complete the analysis and get the report out in as short a time as possible after the survey—normally two or three days. It is rare for signal action to be required because particularly bad machines will normally be noticed and the ship informed at the time of the survey.

Analysis of Data and Reports to Ships

The fairing up of data and the analysis of the results takes a similar amount of time as a survey, e.g. about twenty minutes for a motor-driven pump and up to four hours for a turbo-alternator set. The data sheets are forwarded to the ship together with a precis of the analysis and any resulting recommendation. Copies of the report are also sent to the engineering staff of the area flag officer.

Application of VA Techniques to Reciprocating Machinery

The FVAU has been confident of its ability to diagnose data on rotating machinery for some time but reciprocating machinery has been a grey area. It is only within the last few months that warning levels have been established in this field and that frequencies have been related to various aspects of condition.

For instance, it is recognized that high levels of vibration at a frequency of half engine speed will be caused by combustion problems on a four-stroke engine; high levels at frequencies equal to engine speed are caused by unbalance; and high levels at frequencies of twice engine speed are caused by mechanical looseness. To complicate matters, torsional vibrations appear at frequencies of $1\frac{1}{2}$, $2\frac{1}{2}$, and $3\frac{1}{2}$ times engine speed and at other frequencies depending on the number of cylinders.

This appears to be a sound basis for analysis but experience shows that slight unbalance will be exaggerated by poor combustion, and also mechanical looseness by unbalance. It follows that, before any sound analysis can be made from diesel engine vibrations, the engine must be in a good state of tune with exhaust temperature scatter within the manufacturer's limits. The FVAU maintains a close liaison with the engine manufacturers and confidence in its analysis of diesel vibrations is growing with experience.

Effectiveness of Fleetwide Vibration Analysis

It is not possible to say, after identifying a problem, that had it gone undetected the machine would have failed in service. However, a review of random failure trends is most interesting (see TABLE I). The review covers a period of ten years with the introduction of fleet-wide vibration analysis being at the half-way point. The information is taken not from the FVAU records but rather from the records held by the equipment desks of the Fleet Engineering Staff at Portsmouth and originally collected by the now defunct Ship Maintenance Authority. The equipments were selected at random but, of course, had to have been in service for the full ten-year period.

Overall, an increasing failure trend is apparent up to about 1976 followed by a decrease. Many factors could contribute to the latter, one of which is believed to be the extension of vibration analysis.

TABLE I—*Some failure trends from 1970 to 1980*

	T/D forced lub. pumps 1.16.3 turbine			*350/400kW turbo alternator*			*T/D extraction pumps*		
	Failures			Failures			Failures		
Year	Mech[1]	Other	Total	Mech[1]	Other	Total	Mech[1]	Other	Total
1970	2	3	5	1	1	2	2	–	2
1971	6	3	9	10	7	17	5	3	8
1972	7	2	9	11	17	28	7	4	11
1973	4	2	6	21	11	32	4	6	10
1974	5	1	6	17	10	27	1	2	3
1975	5	1	6	13	9	22	2	–	2
1976	6	3	9	21	13	34	2	2	4
1977	1	–	1	13	9	22	–	3	3
1978	2	–	2	10	9	19	–	1	1
1979	1	–	1	6	12	18	–	–	0
1980	1	–	1	7	9	16	–	–	0

Condition-based Maintenance Policy

The change in maintenance policy to a condition-based system from the familiar calendar-based system has given rise to the need to put simple hand-held instruments into ships. The change in maintenance policy was fully explained in DCI 190/80. The new system is the Maintenance Management System which is being progressively installed in the Fleet.

The two simple instruments required to monitor machinery condition are the VISIN (vibration severity indicator) and the SPM43A (shock pulse meter).

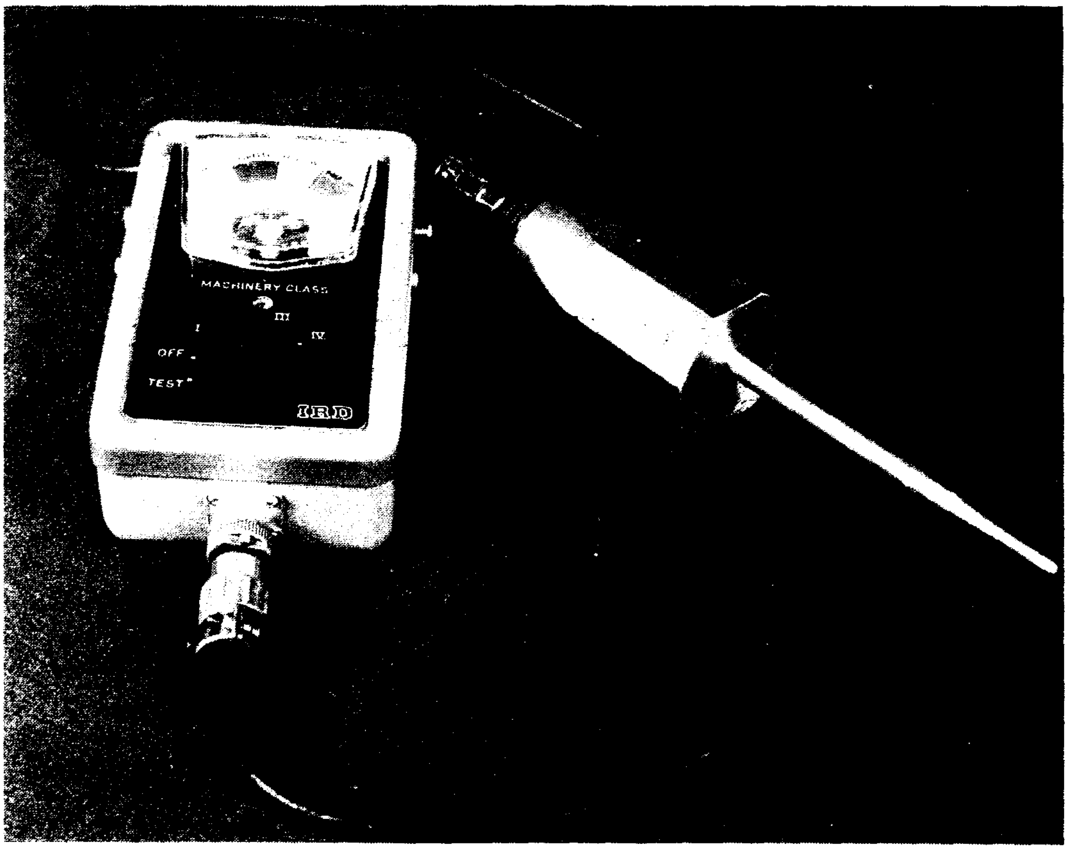


FIG. 1—VIBRATION SEVERITY INDICATOR (VISIN)

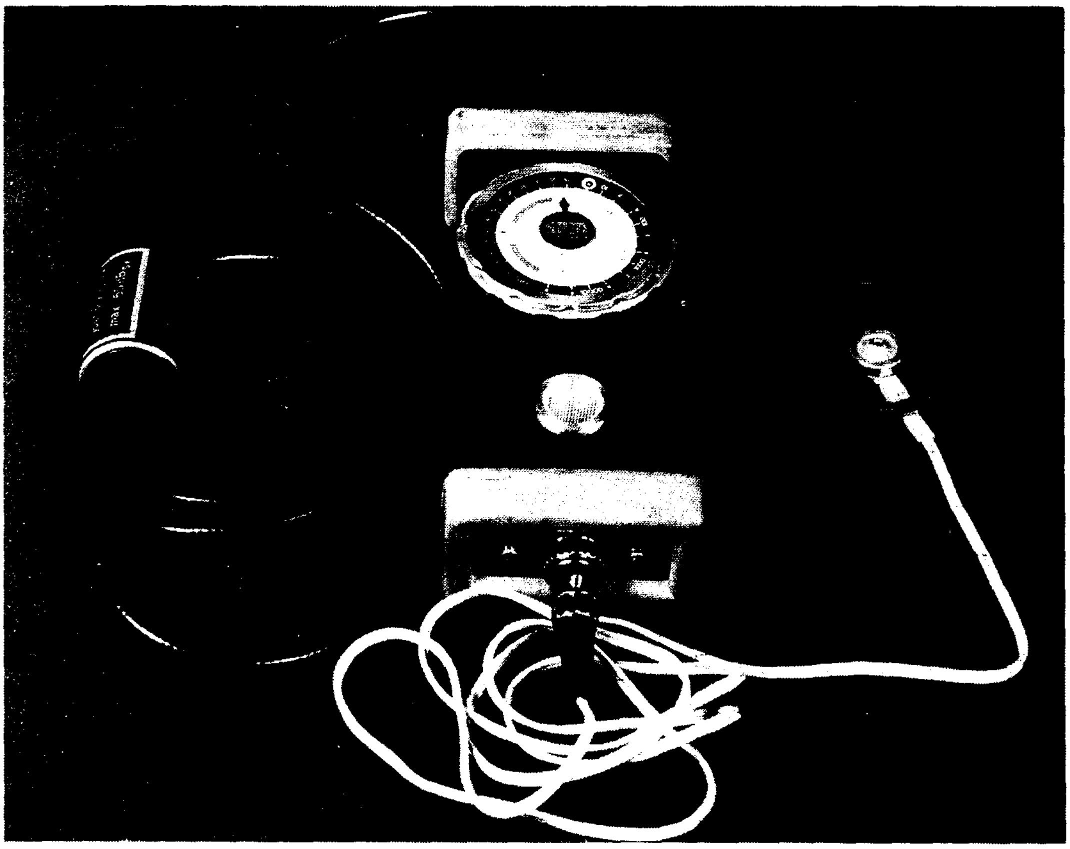


FIG. 2—SHOCK PULSE METER (SPM 43A)

The VISIN

This is a compact battery-operated instrument (FIG. 1) designed to be easy to operate by junior ratings. It has a colour-coded scale allowing the reading to be obtained and recorded simply. It has no analytical capability and is used to monitor overall vibrations at monthly intervals. A rise in level into the yellow zone is a warning and requires action to be taken by ship's staff. If possible, a full discrete survey should be undertaken on the equipment at the earliest convenient opportunity, either by using the ship's own IRD 320 machine or by calling for a special survey by the Fleet VA Unit. Meanwhile the machine must be monitored much more frequently and, if a further rapid increase in the monitored level occurs, the machine should be taken out of service for investigation.

The SPM43A

This instrument (FIG. 2) is used to check rolling element bearings for early signs of deterioration. It is tuned to a frequency of 32kHz which is a typical frequency associated with this type of bearing. As with the VISIN, it is simple to operate and has a colour-coded scale for ease of use. For accurate results, the probe must be applied directly to the bearing housing.

Conclusion

As the experience of personnel and the credibility of VA increases, it is anticipated that real benefits will show. The concept of the engineer making a maintenance decision as a result of VA and other considerations, rather than following a calendar-based programme, is an attractive objective.

From available data, it appears that vibration analysis techniques are a most useful aid to assessing machinery condition and identifying objects.

The early warning of impending problems indicated by vibration analysis has probably prevented many expensive machinery failures.

The availability of simple vibration monitoring instruments in ships should further reduce the number of failures by giving a simple trend indication of machinery condition.

Examples

The following two examples demonstrate how results are achieved and how sometimes the diagnosis may be wrong.

Explanation of the Data Sheet and Analysis

The first two columns of each data sheet are the overall displacement and velocity levels given in micrometres and millimetres per second. The overall level is a technical way of expressing the vibration with which we are all familiar and usually sense with a screwdriver or through the soles of our boots.

The remaining columns record the peak velocities at various frequencies. These are the foundation of the diagnosis. For instance, high radial readings at the fundamental speed of the component indicate an unbalanced condition. Large axial readings at fundamental speed and sometimes second and third harmonics are a clear indication of misalignment. Very high frequencies are most likely to be caused by gear meshing or rolling element bearings. By the use of the vibration identification chart and technical details of the machine, e.g. numbers of gear teeth and types of bearing fitted, etc., accurate assessment of condition can be made and defects pinpointed.

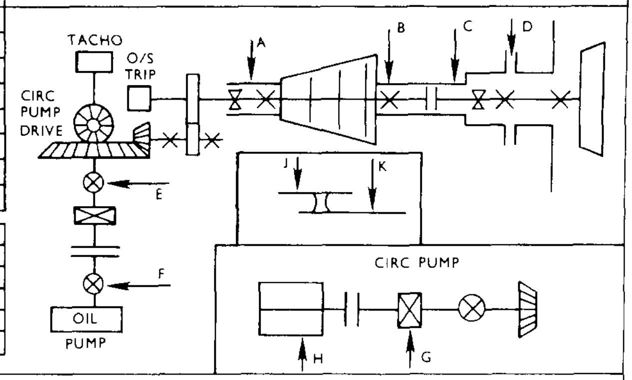
Readings shown as, for example, 10/20 or 4/7 indicate unsteady values varying between the limits given. Axial readings are indicated as outside the

VIBRATION DATA SHEET

Form VA 321r

HMS	BRISTOL
Date	15·2·80
Equip Used	350 No. 3 (B)
Operator	MEMN (P) MORRISON
Main Assem RPM	2200
Sub Assem RPM	
BR No	3395
E.T.M.	

MACHINE:- F/D BLOWER Allens



SYMBOL	IDENTIFIES
——→	Pickup Point
×	Plain Bearing
⋈	Thrust Bearing
⊗	Anti-frict. Bearing
—| |—	Coupling

PICKUP POSITION		FILTER OUT		FILTER IN											
		MIC	mm/s	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM
A	H	15/20	2·5	1·9	2·5K			·5	4·5K						
	V	4	·5												
	A	50	6	·4				1				·4	55K		
B	H	10/20	1·6	4/7		1·2	2·5	1·2				·6	53K		
	V	12	1												
	A	50	5·9	4·8				·8				1	35K		
C	H	13	2	1·5				1							
	V	40	2	1·6				·5							
	A	30	4·6	4				·9		·5	8K				
D	H	70	11	8·6				3				1	50K		
	V	50	7	6				·9				·8	50K		
	A	N/A													

NOTE:- H = Horizontal V = Vertical A = Axial P = Probe N/A = Not Accessible

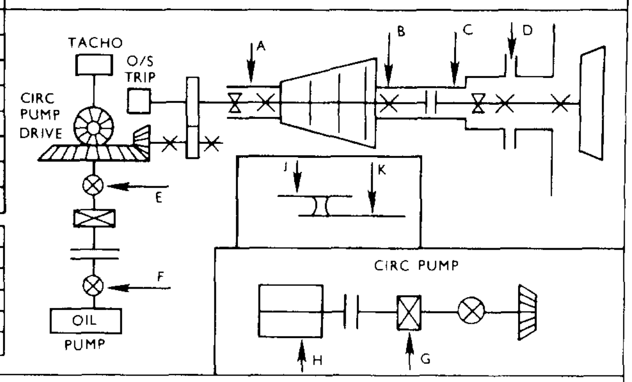
FIG. 3

VIBRATION DATA SHEET

Form VA 321r

HMS	BRISTOL
Date	25·3·80
Equip Used	350 No. 3 (B)
Operator	MEMN (L) VASS
Main Assem RPM	2700/3500
Sub Assem RPM	
BR No	3395
E.T.M.	

MACHINE:- F/D BLOWER Allens



SYMBOL	IDENTIFIES
——→	Pickup Point
×	Plain Bearing
⋈	Thrust Bearing
⊗	Anti-frict. Bearing
—| |—	Coupling

PICKUP POSITION		FILTER OUT		FILTER IN											
		MIC	mm/s	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM
A	H	30	4·4	3	2·7K			·8	9K						
	V	20/25	4	1·7				·7							
	A	20	4	1·8				·7				·4	18K		
B	H	15	2	1·2											
	V	30	2·8	3	2·7K			·8				·8			
	A	N/A													
C	H	20	4	1·4	2·8K			·5	9K			·6	18K		
	V	26	4	3	2·8K										
	A	20	5	2/3	3K			·4	9·4K			·6	14K		
D	H	30	6·4			4	3·6K			·8	11·5K				
	V	30/40	7·2			2·3				1·2	11K				
	A	32	6·4			5·6									

NOTE:- H = Horizontal V = Vertical A = Axial P = Probe N/A = Not Accessible

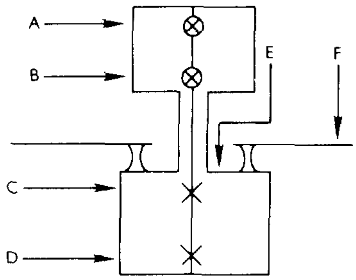
FIG. 4

VIBRATION DATA SHEET

Form VA 415 w 1415e

HMS ARIADNE	MACHINE:- FEED TRANSFER PUMP Drysdale WEE-MAC 2"/2" V.G.S.61,2
Date 25-9-79	
Equip Used No3 350 (B)	
Operator MEMN WALSEY	
Main Assem RPM 1750	
Sub Assem RPM	
BR No 3490, 3408, 2111 (9)	
E.T.M.	

SYMBOL	IDENTIFIES
——→	Pickup Point
✕	Plain Bearing
⋈	Thrust Bearing
⊗	Anti-frict. Bearing
—┤├—	Coupling



PICKUP POSITION		FILTER OUT		FILTER IN											
		MIC	mm/s	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM
A	H	100/200	3/10	·9	820	6/10	1·8K	2	3·6K	1·9	5·5K	2·5	8·6K	2·1	36K
	V	60	7·8	·6		5·7		2·4		2·5		1·4	7·2K	1·9	
	A	N/A													
B	H	120	19			16		3·6				2·4	8·6K		
	V	130	18			17		2·1						1·7	
	A	60/70	6/7			4·2		2·2		1·4		·7	7·2K		
C	H	130	15			10		1·8		3		1·4			
	V	N/A													
	A	N/A													
D	H	200/310				29		6		3·4		2·2			
	V	N/A													
	A	70/80	9			3·4		1				1			

NOTE:- H = Horizontal V = Vertical A = Axial P = Probe N/A = Not Accessible

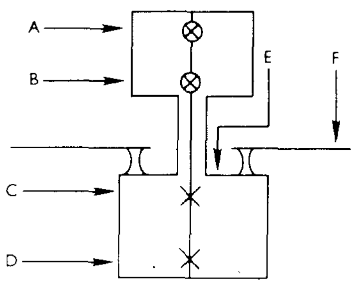
FIG. 5

VIBRATION DATA SHEET

Form VA 415 w 1415e

HMS ARIADNE	MACHINE:- FEED TRANSFER PUMP Drysdale WEE-MAC 2"/2" V.G.S.61,2
Date 27 OCT 80	
Equip Used 350 Nil	
Operator VASS	
Main Assem RPM 1750	
Sub Assem RPM	
BR No 3490, 3408, 2111 (9)	
E.T.M.	

SYMBOL	IDENTIFIES
——→	Pickup Point
✕	Plain Bearing
⋈	Thrust Bearing
⊗	Anti-frict. Bearing
—┤├—	Coupling



PICKUP POSITION		FILTER OUT		FILTER IN											
		MIC	mm/s	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM	mm/s	CPM
A	H	22	2·1												
	V	18/20	3·4	1·7	1·8K	2·1	35K								
	A	7/9	1·6												
B	H	18	1·9												
	V	12	1·2												
	A	10	1·1												
C	H	30	2·7	2·7	1·8K										
	V	23	2·3												
	A		N/A												
D	H	30	2·7	2·7	1·8K										
	V	12	3·2	2·6	"	1·8	35K								
	A	10	1·3												

NOTE:- H = Horizontal V = Vertical A = Axial P = Probe N/A = Not Accessible

FIG. 6

acceptable limit if their value is more than 50 per cent. of either of the other two readings for that particular frequency, e.g.:

H = 1·5, V = 1·6, A = 4·0. A being greater than ½(H) or ½(V) is outside the acceptable limit.

Example 1—H.M.S. Bristol: *Forced Draught Blower*

FIG. 3 shows a data sheet from an actual survey carried out on a forced-draught blower in H.M.S. *Bristol.* The high axial readings recorded at a frequency of 2·5k were thought to be caused by misalignment. This conclusion was reached because:

(*a*) in the vast majority of cases where high axial vibrations are experienced, the cause is misalignment;

(*b*) it was well known that the turbine rotor had been renewed and a new epicyclic gearbox had been fitted after finding that the locating pin in the old one had cracked its mounting plate.

Although it was realized that high axial readings can be caused by unbalance particularly with overhung rotors, it is good practice to check alignment first. As a result of this survey, the alignment of the turbine to the impeller shaft was checked and found to be satisfactory.

A further vibration analysis survey was then carried out producing similar high axial readings. Although the diagnosis still indicated that the blower was suffering from misalignment, the fact that the readings were higher at the blower end increased the possibility that the impeller was bent or out of balance. This had not been considered previously because the impeller was known to be in a good state before the turbine and gearbox change and had not been disturbed. The end of the story was that a foreign bolt was found to be embedded in dirt in the impeller inner annulus. The result of the vibration analysis survey after the removal of the bolt is shown in FIG. 4.

Example 2—H.M.S. Ariadne: *Feed Transfer Pump*

FIG. 5 shows many high radial readings recorded throughout the feed transfer pump during the pre-refit survey of H.M.S. *Ariadne.* As a result, the ship was recommended at the first opportunity to:

(*a*) check the security and condition of the impeller;

(*b*) check the top bearing bush and lantern ring for damage and wear;

(*c*) check the pump shaft for damage and wear;

(*d*) rebalance the motor and pump.

When the machine was opened, the pump shaft was found to be very worn but the motor was in good condition despite the high readings at points A and B. The analyst had been proved correct in deciding that these high vibration levels were transmitted from the defective pump. This is very common in centre-mounted vertical pumps of this type. FIG. 6 shows the survey readings after repair.