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by

B. W. WASHBURN

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

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TURBOPUMP VIBRATION MEASUREMENTS AT CRYOGENIC TEMPERATURES*

by B. W. Washburn
Staff Member
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

ABSTRACT

Wide band acceleration instrumentation techniques for the Rover ground test facility dual liquid hydrogen turbopump system are described. Information bandwidths to 50 kHz have been utilized to study structural and flow induced vibrations. Transducer environments vary from 530 to 114 degrees Rankine with complex acceleration levels up to 2,000 g's pk-pk.

INTRODUCTION

The Los Alamos Scientific Laboratory Rover nuclear rocket ground testing facility in Nevada utilizes high speed turbopumps, developed by Rocketdyne, to supply liquid hydrogen propellant to the reactor under test. Two turbopumps are arranged such that they may be operated in single or dual mode (parallel) to furnish flow rates up to 350 pounds per second of liquid hydrogen at 1,500 psig. Each turbine is rated at 25,000 horsepower and 34,000 rpm. See Figure 1. The turbine energy source is hydrogen gas produced in a bootstrap operation of the turbopump by a hot water-to-liquid hydrogen heat exchanger.

Several circuit configurations and bandwidths have been applied by Los Alamos Scientific Laboratory in making vibration measurements on this turbomachinery. Routine vibration measurements on the pump, turbine and duct components have 1,000 Hz bandwidth, the frequency range of structural and rotational speed-connected components of interest. Channels extending to 50 kHz have been utilized to define the vibration spectral environment to which the sensors on the 1,000 Hz channels are subjected and to study flow induced vibrations.

BASIC MEASUREMENT PROBLEMS

Testing of turbopumps earlier in the Rover program had indicated the presence of vibration components of relatively large amplitudes at frequencies above 1,000 Hz. The larger system currently in operation has a more severe environment in this respect. Vibration components above 1,000 Hz are of the order of 40 db greater in level than the components below 1,000 Hz. Presence of the large amplitude,

high frequency accelerations gives rise to mechanical and electrical problems in making the lower frequency measurements. The complex composite vibration motion must be followed linearly by the transducer and mounting. Peak forces on a one ounce assembly can be of the order of 40 to 70 pounds under these environmental conditions making necessary a very rigid installation of the transducer to insure mechanical linearity. High frequency components present may excite the transducer resonances. The electrical output of the transducer must be transformed linearly with good signal-to-noise ratio until the unwanted frequency components can be removed.

The pump and ducting measurements are made at locations where the transducer temperatures are around 114 to 140 degrees Rankine. Compatible material properties at these low temperatures are essential to maintaining the necessary rigid sensor installation.

MEASUREMENT

Transducer

All measurements utilized a single ended compression design, quartz element accelerometer. A one ounce unit, Endevco Model 2242-C, having a mounted first resonance over 33 kHz was used up to 10 kHz. For higher frequencies a unit of similar design, Endevco Model 2274, weighing 0.3 ounce and having a first resonance above 75 kHz was used.

Units of this particular design had previously undergone limited testing in the laboratory at 38 degrees Rankine (LH_2) and had been used on three earlier LH_2 pumping systems by Los Alamos Scientific Laboratory. An approximate theoretical analysis was performed on the transducer to estimate its performance at the low temperatures and high 'G' levels. From room temperature to 139 degrees Rankine the sensitivity decreases about 2.5% due to Young's modulus variation and the linear amplitude range is approximately doubled.

These transducers have a 303 stainless steel case which may or may not undergo a permanent dimensional change at cryogenic temperatures, around $1N_2$, due to crystal transformation. A 100% transfor-

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mation results in approximately 4% increase in dimension. The transformation, if it occurs, is usually around 5 to 10% making the dimension increase of the order of 0.2 to 0.4%. Transducers are temperature cycled between room temperature and IN_2 prior to use to ensure stabilized dimensions.

Mounting Transducers

Figure 2 shows a typical accelerometer mounting. All mountings are directly in flanges or cases and utilize a standard insulated mounting stud Endevco 2980B, for the 2242-C unit. Insulation is epoxy and fiberglass and the stud material is 416 stainless steel.

The following mounting tolerances were design objectives: 1.) perpendicularity of stud hole to accelerometer mating surface within 15 minutes of arc, 2.) flatness of mounting/mating surface within ± 0.0005 inch, 3.) mating surface finish equal to or less than 16 microinch RMS and 4.) class 3 threads.

The pump case is 310 stainless, the stud is 416, and the accelerometer is 303. Analyses of tolerances and dimensional changes of these three materials at the low temperatures indicated that some loosening of the mountings was a possibility. The uncertainty here is due to nominal thread dimensional tolerances and the inability to accurately calculate the tension in the small mounting studs. Several studs of 303 stainless were tried on the pump. Qualitative performance of the complex waveform was the same as with the 416 stainless steel stud.

In mounting the transducer it seems advisable to keep in mind that the actual mounting of the transducer is really the final mechanical assembly step of the unit and as such this operation should be carried out with somewhat the same care used in building the transducer. All surfaces and threads are thoroughly cleaned with alcohol and dried prior to assembly. Mounting torque is 18 to 25 inch-pounds.

Cable

Standard low noise, teflon insulated Microdot cables are used with a silicone compound seal at all connectors. Cables are not fastened to the turbopump system at the transducer end due to mechanical details of the pump case insulation. Instead a short length of heat shrink tubing is applied over the connector and cable at the transducer.

Amplification

A voltage system is used. This choice is influenced by 1.) the need to transform linearly the complex transducer output signal while eliminating the large amplitude frequency components above the frequency range of interest and 2.) the transducer charge sensitivity and capacitance variations at low temperatures. The 1,000 Hz channels use a Dynamics Instrumentation ac amplifier, Model 6163, with a third order low-pass filter in the input.

The input filter attenuates the high frequency components prior to signal amplification and minimizes the likelihood of these components driving the amplifier into nonlinear operation. These units have a high impedance, low capacitance input.

Channels having greater than 1,000 Hz bandwidth utilize a cathode follower driving a fourth order active filter.

All voltage amplifiers and filters are located in the turbopump area such that the transducers typically drive fifteen feet of Microdot cable. With the cable and amplifier load, the voltage sensitivity is decreased by 3% at 139 degrees Rankine making a total sensitivity decrease of the order of 5.5%.

All signals are FM recorded on magnetic tape for post test reproduction and analyses.

Calibration, Set-up and Check-out

Procedures were evolved to insure channel integrity with minimum handling of the elements. Laboratory calibration is performed at relatively low "g" levels and room temperature with cable and amplifier combination. Initial installation, pre-test and post-test check-outs are performed using series voltage insertion without breaking connections or removing the transducers. Mounting torques are checked before and after a test without loosening to prevent foreign matter from accidentally entering the mounting. Exposed cables are visually inspected for mechanical damage and are checked for noise generation by manually flexing while observing the amplifier output on an oscilloscope. Pre and post test checks are made for proper circuit isolation. Removal of circuits, cables, mounts, etc is not considered as routine. This is done only for major system mechanical work or when a component is definitely proven defective.

EXPERIENCE

With one year of operational test experience there has been one transducer failure (crystal stack insulator fractured during post-test warm up from cryogenic temperatures) and two mounting stud insulation bond failures which occurred in post-test periods. The only known cable problems have been damage inflicted during routine work on the system. Cables are in conduit except for about a one foot length at the transducer end.

Transducers mounted on scored and unfinished mating surfaces have consistently produced clipped or distorted waveforms in this system. Similar behaviour has been noted when mounting threads were dirty.

Establishing ranges for these channels has been a problem. As the pumps, turbines, and inlet ducting have been replaced during the course of these development tests, the system resonant frequencies have shifted to a degree but the changes in resonance amplitudes were most dramatic. Amplitude changes by factors of two to ten were not uncommon. Also, transducer locations vary on the different pumps

and turbines used.

Transducer torques have been checked with the system cold and no significant loss from the room temperature value has been observed.

Vibration levels and frequencies were plotted on the pump map for correlation with pump flow, discharge pressure, and speed. See Figure 3. Components below 1,000 Hz usually correlate with speed while those above 1,000 Hz correlate with liquid hydrogen flow rate. While it is difficult to generalize, some predominant components and typical levels are given in Table 1.

TABLE 1

FREQUENCY (Hz)	TYPICAL RANGE (g's pk-pk)
250	1-7
525-535	5-60
1000	50-270
1141	16-130
1600	75-780
4000	120-420
6300	70-1260
8000	200-1075

This is by no means all resonances or components observed as tests on the system have shown over twenty resonances below 1,000 Hz.

High 'Q' responses have been observed at the turbine case between 12,600 and 20,000 Hz. Levels between 600 and 2030 g's pk-pk have been recorded. The only correlation at present for these flow noises is turbine speed. More tests are planned to check dependence upon turbine power and to define turbine case modes at these frequencies. These components are of interest since some stages of the turbine have blade resonance modes in this region.

SUMMARY

High level vibrations and cryogenic temperature environments necessitate care in measurement component selection, installation, and signal processing. Spectrum conditioning of the complex composite vibration signal prior to amplification is necessary to remove large amplitude, high frequency flow excited components when measuring low amplitude, low frequency structural, and speed connected components.

FIGURE 1. TURBOPUMP SYSTEM

FIGURE 2. TYPICAL ACCELEROMETER INSTALLATION

FIGURE 3. TURBOPUMP MAP