SALES AID MEMO #12

March 1, 1973

THE TERRY STEAM TURBINE COMPANY

TO: ALL PRICEBOOK HOLDERS: MR. G. Kniep

SUBJECT: TERRY WHEEL WATER SLUG TEST

As many of you know, we were required to run water slug tests on a CCS turbine for nuclear service several years ago. These tests were conducted in our shop, and to say that they were dramatic is putting it very mildly. Because of conditions that could exist in the reactor, the tests took two forms:

A. The turbine was started with a slug of water against the quick open valve backed by steam pressure.

B. The turbine was running on steam pressure when a controlled slug of water was fed through it.

During these tests, the turbine exhausted through an open pipe poking out a back window of the shop. When large slugs of water were used, liquid water would fire out the exhaust pipe for distances up to several hundred feet. The forces involved in this test were truely awesome.

After the tests the turbine was torn down for a complete internal inspection, and no detrimental effects were found. The test was a complete success, and that very turbine has subsequently gone into service.

Until recently, we could not publish these test results because of commercial considerations. This information is now released, and we can make any use of it that we wish.

Attached is a copy of the formal test report. This can be shown to any customer and reproduced either in whole or in part. Additional copies are available for your use on request.

K E Barrett
K. E. Barrett
Sales Manager

KEB/jkp
Attach.

WATER INJECTION TESTS
SOLID WHEEL TURBINE

1. Purpose of Tests:

To prove empirically the paper analysis that predicted no damage would result to a SOLID WHEEL turbine as the result of a cold quick start with a water slug in the steam line adjacent to the stop valve or when this same water slug was transmitted to the turbine by the steam line during normal operation.

In defining the above, a series of tests were conducted on a Terry SOLID WHEEL steam turbine to prove that such water slug would cause no damage to the pressure boundary and no permanent degradation of performance of the turbine. The test involved both a series of quick starts with varying quantities of high pressure hot water against the stop valve and a separate series in which various quantities of water were injected into the turbine while it was operating under rated speed and load.

2. Conclusions:

The following conclusions were apparent:

A. The test conditions to which the turbine was subjected were as severe as could be expected in even a waste heat boiler application where control of the water level was lost or the boiler started "perking".

B. The turbine showed no signs of damage and suffered no permanent performance degradation as a result of these tests.

C. The tested turbine is typical of the SOLID WHEEL turbine presently provided by the Terry Steam Turbine Company for the nuclear industry, marine industry and stationary service.

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3. Background of the Test Work:

All turbine users have been faced with the possibility of water carry-over in a steam line causing distress to a steam turbine, either physically or to degrade its performance. In analyzing the problem, especially with quick-start turbines, it was concluded that two separate types of water slug tests would be required to prove that a turbine could "ride through" such water slugs. These would be as follows:

A. At the time of a quick start (defined as opening a quick-acting valve in the steam line to a cold turbine) for one reason or another the steam line to the turbine was found to be full of water, this water would have to pass through the turbine before the unit could operate normally. The steam line to such a turbine is normally drained, but the water slug could be developed either by failure of the draining components or by the fact that water entered the line faster than it could be drained out.

B. An alternate difficulty would be encountered if the turbine should have to "swallow" the water slug while it is operating normally. This could occur if a boiler or waste heat steam generator water level goes "over the top" putting water in the steam line to the turbine.

For a complete understanding and resolution of the concerns expressed, full-scale tests were conducted to simulate both assumed conditions.

4. Damage Potential:

Any damage to the turbine because of water ingestion would be the result of impingement forces either overstressing and breaking components or overloaded and failed bearings. As a general rule, the potential for

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damage due to impingement forces increases as sub-cooling of the fluid being discharged from the high pressure region increases. It was thus decided to perform the water slug test with highly sub-cooled water, higher than could be expected to exist in any conventional steam system.

5. Test Set Up:

The turbine selected for the test was a two-wheel (helical solid wheel) steam turbine, Type CCS, as manufactured by The Terry Steam Turbine Company of Windsor, Connecticut. This turbine is of the impulse, helical flow type, and is used primarily for non-condensing operation. The machine selected for the test was a normal production unit, scheduled to be installed in an auxiliary safety system of a nuclear power plant.

The test set up is shown schematically in Figure 1. Inlet steam was supplied from a 900 psig test boiler, desuperheated to about 600 psig saturated, and led into the test tank area where it was either Teed off into the test tanks or by-passed and led back to the test floor to the turbine stop valve. The test tank was designed to hold a maximum of 600 gallons of water. Steam inlet pressures and temperatures were measured immediately before the turbine stop valve. Exhaust from the turbine was to atmosphere, with pressure and temperature taken in the turbine exhaust casing. In addition, the turbine shaft vibration, turbine speed, and turbine control valve stroke were measured.

All tests were performed at The Terry Steam Turbine Company, Windsor, Connecticut plant.

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6. General Operation Tests:

Two series of tests were run. The turbine was connected to an inertia load that was representative of the service in which the test turbine was to operate. In both series of tests, steam of approximately 600 psig acted as a driving force for the water injection.

The purpose of the first series of tests was to demonstrate the turbine's capability to start up with various quantities of water against the stop valve, with the turbine reaching normal operation on saturated steam after the water had passed through the turbine. Water quantities ranged from 50 to 600 gallons.

The purpose of the second series of tests was to demonstrate the capability of the turbine to accommodate various quantities of water injected into the steam line while the turbine was running at rated conditions, with the turbine returning to normal operation on saturated steam after the water transients. Water quantities were the same as for the first series of tests.

Following both series of tests, the turbine was completely disassembled and all parts inspected for possible damage or deterioration. After reassembly of the turbine unit, a no-load running test was scheduled so as to detect any degradation of turbine performance as a result of the water start up and injection tests.

7. Test Results:

A. Quick start test:

Four test runs were performed with water quantities increased from 50 to 600 gallons. Water ingestion by the turbine generally re-

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sulted in a momentary drop in the inlet pressure, followed by a short peak in the exhaust pressure. As an example, the water start-up transients with the maximum amount of water (600 gallons) is depicted in Figure 2. As shown in this Figure, after the water had passed through the turbine (approximately 21 seconds), the turbine operated normally on saturated steam. In all test runs, the turbine's vibrations were so slight that they did not register on the recorder.

B. Water injection tests:

In this series of tests the sub-cooled water was injected into the steam line feeding a normally running turbine, three tests being made with increasing water quantities from 50 to 600 gallons injected. As the test showed, the response of the turbine governor to water injection during operation was to fully open the control valve in an attempt to maintain speed. This action resulted in a sharp inlet pressure drop and exhaust pressure peak, whose numbers and frequencies increased with increasing amounts of water. The turbine transient with the maximum injected quantity of water (600 gallons) is depicted in Figure 3. As shown in this Figure, the turbine returned to normal operation as soon as the water had passed (approximately 10 seconds). Again, the turbine vibrations were not sufficient to be registered on the recorder on any run in this series.

Both series of tests clearly demonstrated that the SOLID WHEEL steam turbine was able to return to normal operation by itself, having suffered no detrimental effects.

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8. Inspection:

After completion of the turbine water start up and injection tests, the turbine was completely disassembled and examined for excessive wear or deformation. Visual, die check, and dimensional measurements of the steam chest, valves, sealing glands, bearings, rotor, casing, nozzles, shaft, and other components indicated that no damage whatsoever occurred. The turbine was then re-assembled and satisfactorily retested under no-load conditions.

9. Adequacy of Tests:

To demonstrate that the tests are representative of the conditions to be expected in service, it must be shown that the following parameters had acceptable values:

- Water Flow Rate
- Total Amount of Water Ingested by the Turbine
- Thermodynamic Conditions of the Water
- Inertial Turbine Loading
- Machine Size

In the following discussion, it will be shown that each of these parameters was adequately accounted for in these tests.

A. Water Flow Rate

The water flow rate into the machine determines, largely, the magnitude of any impingement load. The water flow rate is determined by the upstream pressure and the thermodynamic conditions of the water. As discussed in 9.B below, the water that could enter the steam line of an operating auxiliary turbine system would be essentially saturated and would have a maximum pressure determined by the relief

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valve set point. The maximum flow rate into the turbine for this saturated liquid would correspond to Moody* critical flow occurring through the fully open control valves. The maximum flow rate of highly sub-cooled water ingested into the turbine during the tests corresponds to Bernoulli's flow through the fully open control valves. Calculations show that this flow rate was about 50% higher than the maximum flow rate that could enter an installed unit. It can thus be concluded that the tests adequately reproduced the expected water flow rate.

B. Total Amount of Water

The maximum amount of water (600 gallons) that was dead-ended at the turbine stop valve in the first series of tests represents a typical turbine steam line full of water. This amount is considered sufficient to duplicate the worst case to be expected in any service. Thus, it is concluded that the quick start up and the water injection test, each with 600 gallons, was an adequate demonstration of the ability of the SOLID WHEEL turbine to withstand water ingestion. It should also be noted that in terms of stress cycles, the repeated turbine tests using various amounts of water represent far more severe conditions to the turbine than one operating upset with the same total amount of water.

C. Thermodynamic Conditions of the Water

For both series of tests, the highly sub-cooled water injected into the machine was about 240°F and 600 psig. Any water that enters

*Moody, F. J., "Maximum Two-Phase Vessel Blowdown from Pipe", General Electric Company, Atomic Power Equipment Department, April 1965, APED-4827 the steam line would be essentially saturated. With the exception of the valve immediately before the stop valve, all of the valves in the steam line are all normally open. The line would be hot at the time any liquid might be entering and would not be capable of taking energy from the liquid. Hence, there is no mechanism by which the fluid reaching the turbine could be significantly sub-cooled. As the saturated liquid or two-phase mixture enters the turbine and depressurizes, it will immediately begin to flash and expand, whereas a jet of highly sub-cooled liquid is more likely to break something than a wide jet of "slushy" two-phase mixture, not only because of the size of the jet, but also because the mass flow rate is higher and the total impingement load greater. Thus, as a general rule, it can be said that the potential for impingement damage increases as the sub-cooling of the fluid being discharged from the high pressure region increases.

Although the test pressure was only about half of the maximum operating pressure possible, the primary influence of pressure is on the flow rate into the machine; and it has been shown that the tests were more severe in this respect than would have been encountered at design pressure.

It is concluded that the tests were much more severe than the maximum pressure case in terms of the thermodynamic condition of the liquid ingested by the turbine.

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D. Turbine Loading

The inertial loading on the turbine that was tested was representative of a typical auxiliary pump; thus transient response of the machine should be similar to the response which would actually occur. The lack of a pumping load would not have a significant difference to the impingement loads on the turbine because in the test, as well as in an installed unit, the turbine control valves went fully open during the water transient in order to maintain turbine speed. Thus, the water flow rate was the maximum possible. Hence, it can be concluded that the tests were conducted with a turbine loading condition that was adequate.

E. Machine Size

The tested machine was a two-wheel production unit. Differences between auxiliary drive turbines for different plants are mainly of physical size. Large machines use a double wheel turbine, but have different nozzle sizes. A single wheel machine is used for smaller sizes.

Although a two-wheel turbine was tested, the single wheel turbine is inherently more capable of withstanding the water injection tests. There is less energy input to the single wheel machine. Furthermore, the "weakest" point in the turbine design is the overhang of the inlet steam nozzles; the single wheel unit has less overhang, therefore, less moment; therefore, less potential for failure. There is no technical reason for suspecting that a single wheel machine would fail to pass the water injection tests.

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Thus, it can be concluded that the test unit and the test results achieved with this unit are representative for all Terry Steam Turbine Company SOLID WHEEL turbines.

All data presented were personally witnessed and are certified to be accurate by the undersigned.

V. E. Bochnak
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THE TERRY STEAM TURBINE COMPANY

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