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DARLINGTON NGD FUEL HANDLING

HEAD EIGHT ACCEPTANCE PROGRAM

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ABSTRACT

Darlington NGD requires eight fuelling machine heads to fuel the 4*932MW reactors. Six heads are used on the three fuelling machine trolleys for normal fuelling operations. A further two heads are required to allow for maintenance and to provide for such reactor face activities as PIPE and CIGAR.

Seven heads were successfully delivered to site from the head supplier. During acceptance testing, stalls on the charge tube screw assembly of the eighth and final head prevented its delivery to site. Replacement of the charge tube screw with a spare screw did not alleviate the problem.

An in depth series of tests were undertaken at site, at the supplier and at the screw sub-supplier to determine the root cause of the problem.

These tests included taking torque measurements under different operating conditions and using different components to assess the effects of the changes on torque levels. An assessment of the effects of changing chemical conditions (particularly crud levels) was also made.

To ensure that the results of the testing were well understood, additional torque testing was also completed on a head and screw assembly at site that was known to work well.

Based on all of the above series of tests, a recommendation was made to re-machine the charge tube screw(s). The original charge tube screw from Head eight was subsequently returned to the sub-supplier for re-work. Follow-up torque measurements and acceptance testing showed that the screw re-work was effective and that Head eight could be successfully delivered to site.

This paper focuses on the results of the head/screw test program. Results of the acceptance testing are also discussed.

INTRODUCTION

The Darlington fuel handling system provides automatic on power fuelling capability to all four reactors. Under normal operating conditions, each reactor unit can be serviced by any one of three fuelling machine (FM) systems.

A fuelling machine system consists of one pair of fuelling machine heads and their associated heavy water and air auxiliary systems all mounted on a transport trolley.

During a typical fuelling operation, one fuelling machine head inserts four fuel bundles into a channel two at a time. This causes the string of 13 bundles in the channel to be shifted and the four end bundles to enter the second fuelling machine head. Either of the fuelling machine heads can insert new fuel or receive irradiated fuel as all the heads are identical (see fig 1).

Each head consists, in part, of a charge tube and a concentric ram which transfers fuel into the reactor under normal operating conditions (310oC and 10MPa). The charge tube has an axial drive (CTA) and a rotary drive (CTR). The ram has an axial drive only.

Figure 2 depicts the layout of a Darlington ballnut/screw arrangement. The charge tube is hollow with the ram positioned inside the charge tube. Both charge tube and ram axial movements are generated through the ball screw/nut arrangement. The charge tube axial drive rotates the charge tube ballnut which is stationary with respect to the fuelling machine. This motion causes the charge tube screw to advance or retract axially depending on the direction of the ballnut rotation. All actions are in heavy water. There is no lubrication (other than the water).

For a ball screw/nut arrangement to work with minimum torque, it is crucial that the balls do not bunch up. Adjacent balls in a screw can come into contact with each other by:

- vibrations
- bending of the screw due to loading
- imperfect screw profiles
- poor deflectors or guides

When any of the above occur, higher torques are required to overcome the bunching up of the balls. An effective ballscrew design will have less potential for ball bunching or if it does have some ball bunching, the balls will separate easily.

DISCUSSION

Six heads are used on the three fuelling machine trolleys for normal fuelling operations. A further two heads are required to allow for maintenance and to provide for such reactor face activities as PIPE and CIGAR.

Seven heads were successfully delivered to site from the head supplier. During final acceptance testing of the eighth head, stalls on the charge tube screw assembly prevented its delivery to site.

Prior to the final acceptance testing, a series of preliminary tests of the head was completed on a test rig that simulated a Darlington fuel channel. During this initial testing, frequent charge tube axial stalls (due to higher than expected torques) were noted. Note that average torques typically seen on an acceptable charge tube are 50-80inch.lbs while peak torques of 150-200inch.lbs were typically seen on Head 8 charge tube.

The fuelling machine was removed from the test rig, disassembled, inspected, cleaned, re-built (with a spare screw/nut assembly) and returned to the test rig for a second series of testing. The original screw/nut assembly was returned to the sub-supplier for evaluation.

During the second series of testing, cold runs (260oC) were successful with no stalls observed. However, when the test rig temperature was increased to 300oC, frequent stalls began to appear. When the drive torque was plotted against time, many torque peaks (as high as twice the average torque) were noted.

Clearly there was a problem with the charge tube assembly.

Although the major efforts were directed at resolving whether the charge screw was the route cause of the problems, it was also felt that the root cause could possible lie with head component misalignment. It should be noted here that Head 8 was at one time overheated when it was used in an unrelated test program.

Ontario Hydro Technology was contracted to perform a series of tests on Head 8. Accelerometer probes were located at several points along the outer housing of the charge tube axial drive (see figure 3[1]). Torque profiles were also generated. A series of thirty two tests were completed. Sixteen of the tests were in advance mode and sixteen were in retract mode. These tests were completed under several different conditions including:

- off channel
- on channel, cold and de-pressurized
- on channel, cold and pressurized
- on channel, cold pressurized with two fuel bundles loaded into fuel carrier.
- on channel, hot and pressurized
- on channel, hot pressurized with two fuel bundles loaded into the fuel carrier

Results of this series of tests[2] appeared to indicate that the high torques seen with Head 8 were not caused by:

- the screw touching at the front end of the fuelling machine
- alignment problems at the rear of the fuelling machine
- the input drive or gear box

The testing did appear to indicate that the higher than expected torques were caused by either pitch/thread depth variations from the front to the back of the screw or pre-loading on the ballnut. In addition, there was evidence of double contact with the balls on the screw thread. This double contact indicated that there was some imperfection in the screw thread profile.

In later discussions, test rig crud levels were raised as a possible additional contributing factor since the rig was predominantly carbon steel with minimal oxygen control.

The evidence now clearly pointed to a ballnut/screw problem and not a misalignment problem.

A set of experiments were then conducted to narrow down the problem further. A series of tests were completed on a ballnut/screw arrangement that was located away from the head on a test bench. Seven variables were altered. These variables included:

- changing the screw (two spare screws were available)
- changing the nut (two spare nuts were available)
- changing the screw bearings
- changing the pre-load on the nut (100lbs and 600lbs)
- changing the cleanliness of the screw (by adding fine particulate crud)
- changing ballnut transfer tube
- changing ballnut deflectors

Results of this testing are shown in figure 4. Two parameters appeared to predominate, screw pre-load and rig cleanliness (crud).

Head 8 was then re-built. The pre-load on the screw was reduced from the normal level of 600lbs down to 100lbs. Efforts were undertaken to ensure that the test rig was as clean as possible. The rig was run for several days with purification flows maximized, As much crud as possible was removed from the rig.

With Head 8 now rebuilt using optimum conditions as determined from the bench testing (lower ballscrew pre-load and with a clean test rig), final head acceptance testing recommenced.

Again, higher than expected torques were observed. This was somewhat disappointing since all the evidence from bench test work had indicated that the problem was well understood and that we had completed effective fixes (although bench test work was not completed at normal temperatures and pressures).

It was now evident that Head 8 was not adequate for normal production use. Further work was required on the ballnut/screw arrangement.

The screw/nut supplier was contacted for further input. The original screw from Head 8 (which had been previously returned to the sub-supplier) was inspected more closely. Indications of double contact on the screw thread were evident. In addition the screw was found to be bent by about 13 thousandths of an inch. Although this bending was acceptable for use in normal fuelling machine operation, it was too far out for a precise grinding operation.

A decision was made to straighten the screw and regrind the screw thread. It was recognized that the screw could be badly cracked or possibly broken during the straightening process. However it was equally recognized that we would not be able to use the screw in the current state. The screw was eventually straightened to within 2 thousandths of an inch but could not be straightened further. A decision was then made to machine the screw straight.

Following the straightening of the screw, the thread profile was re-ground. The material removed from the thread profile was mostly removed in the axial direction (about 5 thousandths of an inch). The depth of the thread was only altered in the area where the depth was shallowest (by about 2 thousandths of an inch).

The screw (with its nut) was then returned for re-building into Head 8.

Subsequent acceptance testing with Head 8 with the re-machined screw was successful. No high torques or stops were observed during the acceptance testing. Head 8 was finally delivered to site during the summer of 1995.

CONCLUSION

During final acceptance testing of the eighth head, stalls on the charge tube screw assembly prevented its delivery to site.

An in depth series of tests undertaken at site, at the supplier and at the screw sub-supplier eventually determined the root cause of the problem to be a badly machined screw.

The screw was returned to the manufacture for re-work which included straightening the screw and re-machining the thread profile.

Subsequent testing of Head 8 using the re-machined screw was successful. Head 8 was eventually delivered to site during the summer of 1995 and is presently available for service.
Because the testing program showed the importance of using torque monitoring as a diagnostic tool, future activities are being directed at developing torque sensing equipment for use on the fuelling machines during normal operation.

ACKNOWLEDGEMENT

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REFERENCES

1. Darlington GS-A Fuel Handling System Technical Document.

2. Head 8 Acceptance Testing Minutes of Meeting dated 11 August 1994.

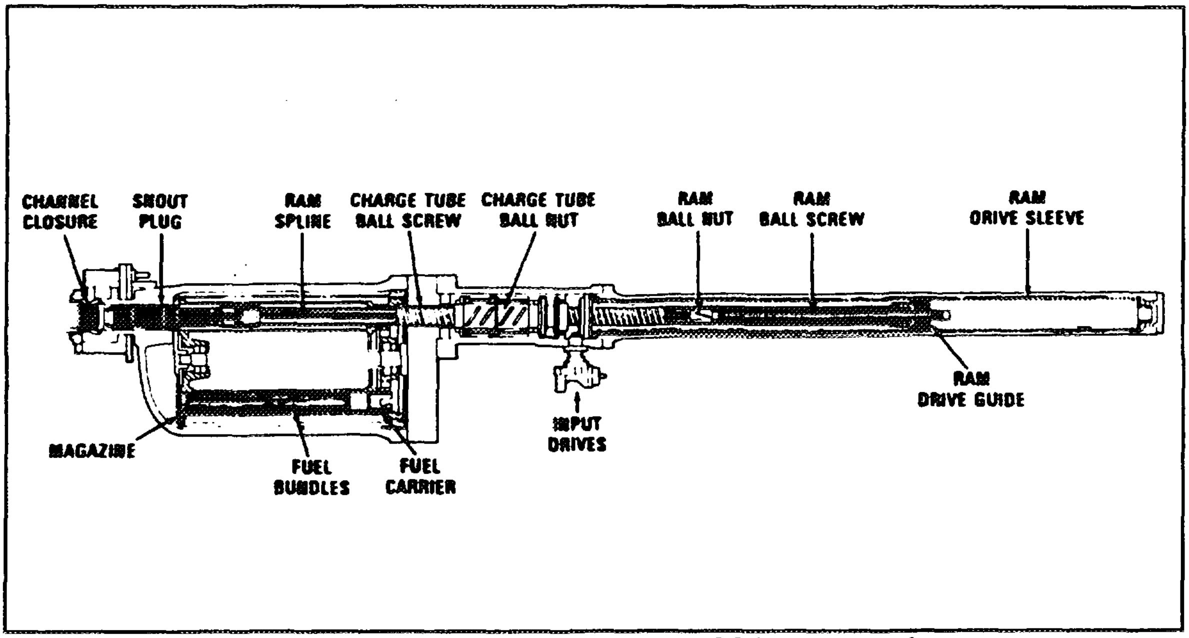

Figure 1: Schematic of Darlington Fuelling Machine.

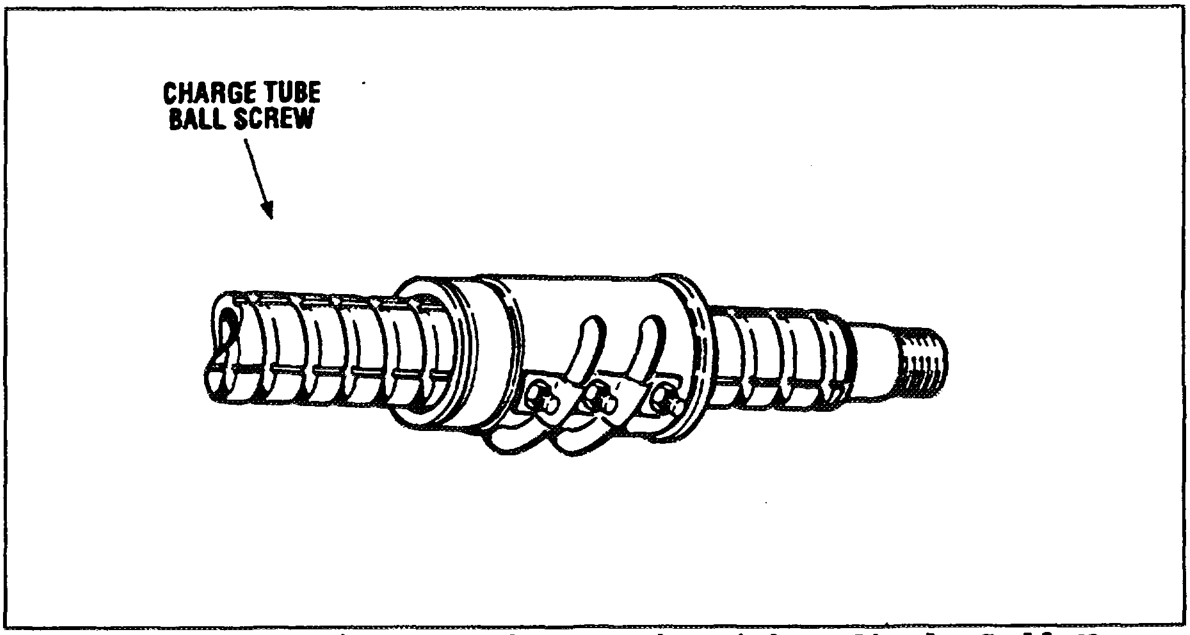

Figure 2: Schematic of a Charge Tube with a Single Ball Nut.

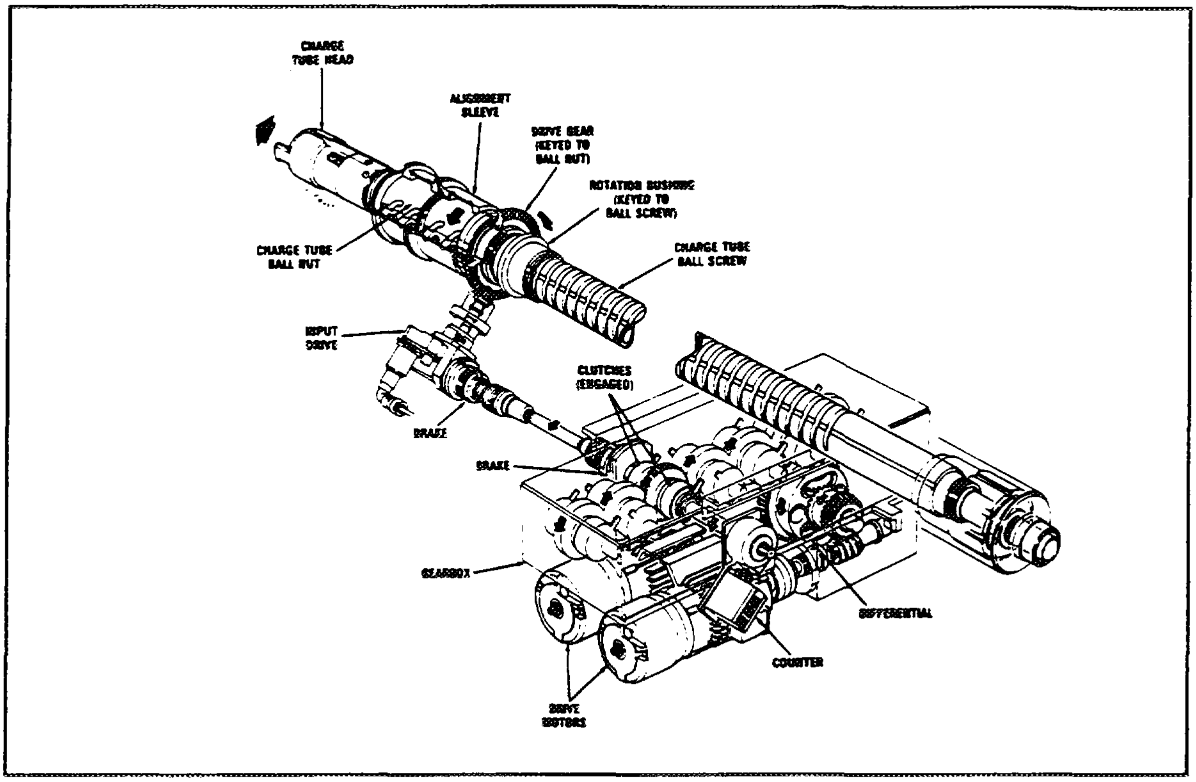

Figure 3: Schematic of Darlington Fuelling Machine Charge Tube Drive Mechanism.

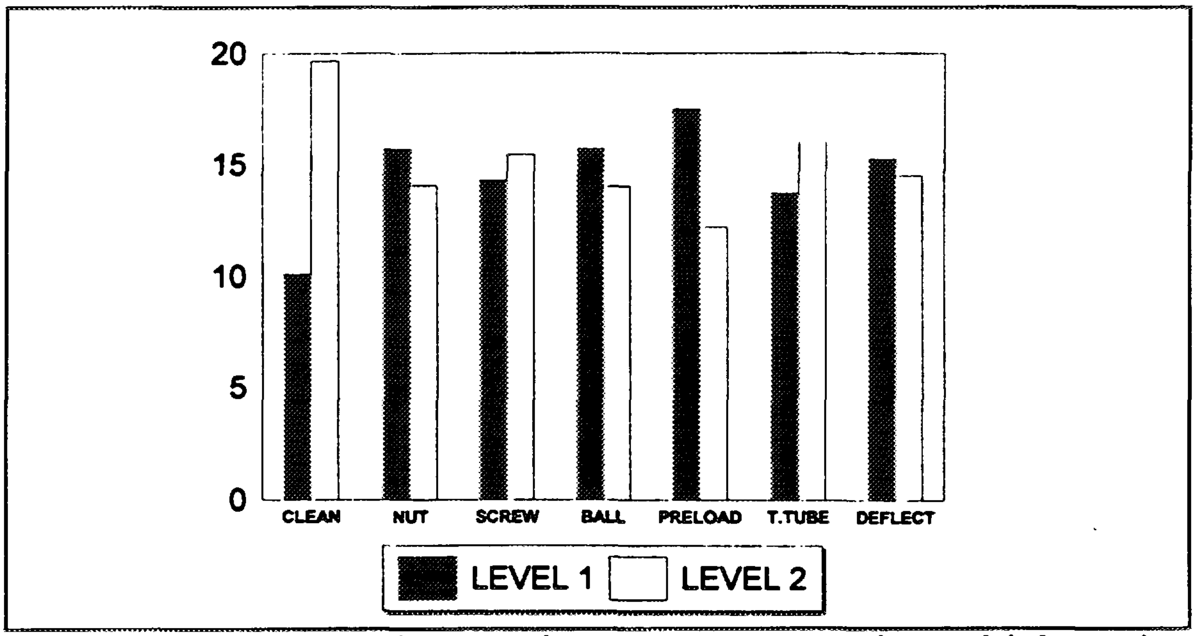

Figure 4: Result of Experiments to Determine Which Major Variable(s) Affect Ballnut/Screw Performance.