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2338 ALASKA AVENUE, EL SEGUNDO, CALIFORNIA 90245

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FAILURE ANALYSIS REPORT

COAL LOCK HOPPER VALVE

MASTER

TYPE III,

P/N 75835, S/N 2

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ABSTRACT

This report covers the analysis of a failure which occurred during static testing of a Type III Lock Hopper Valve P/N 75835. The unit was assembled and acceptance tested at Consolidated Controls Corporation and static tested at the Morgantown Energy Technology Center. After testing at 850°F, the internal leak rate had increased to an unacceptable level. The leakage is felt to be caused by damage to the cast refractory lining used in the valve.

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TYPE III
P/N 75835, S/N 2

INTRODUCTION

As a part of the DOE Program to help develop equipment needed for operation of a synthetic natural gas industry, a contract was awarded to Consolidated Controls Corporation for the design and fabrication of four types of Lock Hopper Valves. The design operating conditions for these four types of valves are shown in Figure 1. Two valves of each type were to be fabricated. The serial number 2 Type III valve was static tested at the Morgantown Energy Technology Center. During this testing, three anomalous events were noted. First, the force required to operate the valve began to increase. Second, the gate did not return to the fully open position. (The gate could be observed by removing the test closures from one end of the valve). Thirdly, the leakage rate increased to an unacceptable level.

The valve was disassembled and two components were found to be damaged. The inlet seat was cracked into two pieces and the gate had failed in the clamp area, where a steel clamp is used to hold the refractory portion of the gate. The inlet seat damage is felt to be tolerable as the inlet seat is not required to seal, but the damaged gate would degrade the performance.

Close examination of the valve body assembly showed small "blisters" in the outlet port. These are suspected to be the source of the increased leakage. Unfortunately, the test apparatus had been removed by METC test personnel, and no verification of this suspicion was made.

These failures are discussed more fully in the remainder of this report.

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DESCRIPTION OF TYPE III VALVE

The CCC Type III Lock Hopper Valve can be described as a parallel sided gate valve with a fixed outlet seat and a spring-loaded inlet seat. A sketch of the general arrangement is shown in Figure 2. The Type III valve is unique due to the very high operating temperature of 2000°F. The choice of materials to operate at this temperature is very limited. CCC has elected to use high-density alumina ceramic for several of the components of the Type III Lock Hopper Valve, including the inlet and outlet seats, the seat loading spring, and portions of the gate. Figure 3 shows several of these pieces, and details of the arrangement. The gate is a composite structure, with a high-density alumina disk used in the sealing portion of the gate, and in the portions of the gate exposed to sliding along the seats. The rest of the gate is made from a "castable ceramic" material called RTC-60*. The RTC-60 is much weaker than the high-density ceramic, and is re-inforced by alumina rods cast into the RTC-60. This method of construction was evolved as a means of combining the high strength and erosion/abrasion resistance of the alumina ceramic with a low-cost, easy-to-fabricate material such as RTC-60. The gate is connected to an electric motor actuator through a steel clamp at one end of the gate, in an area which is cool enough to permit the use of metals. A steel strap is used around the gate, not as a structural piece, but to assist in removing the gate in case of damage.

The valve seals with pressure acting from the inlet side. The gate seal disk is positioned over the fixed outlet seat. A relatively small preload is provided by the ceramic spring. As pressure increases, the disk is forced harder and harder against the seat, an arrangement called a pressure-aided seal. Between the outlet seat and the refractory lining of the valve body is a gasket made of ceramic "paper". This material is not a good sealing material, but is highly deformable and acts to accommodate small irregularities in the mating surfaces.

* A product of the Cotronics Corporation.

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The inlet seat does not seal, but allows pressure to freely enter the valve body cavity.

The other unique feature of the CCC Type III Lock Hopper Valve is the use of a refractory lining to protect the steel body from the high temperature flow media. The inlet and outlet seats are fitted into housings made from a castable refractory concrete, Greencast 94*. These housings are fabricated as separate pieces and ground where needed to obtain the required smooth, precision surfaces. The flow passages are coated with alumina ceramic by a flame-spray process to provide an erosion-resistant surface. These passages are also ground to a precise diameter. Both housings are then placed in the valve body on a mandrel, and accurately positioned by spacers. A styrofoam mold is used to form a recess for the gate, and the entire body is then filled with greencast 94. When the concrete is dry, the tooling is removed, leaving the body as shown in Figure 2.

STATIC TESTING - DESCRIPTION OF FAILURE

The static test procedure is described in METC Information Release Number IR873, dated October 1, 1980. The test consists of a number of cycles described as follows:

- A. The valve is closed, with 1600 psi on the inlet side of the gate.
- B. The outlet side of the valve is raised to 1600 psi.
- C. The valve is opened and then re-closed.
- D. The pressure on the outlet side of the valve is reduced to atmospheric.
- E. The above steps are repeated

This cycle is to be repeated at least 100 cycles at 70°F, and several hundred cycles at elevated temperatures, first at 600°F and then at 850°F. (Temperature in the flow path inside the valve). Records were kept of pressures, leakage, temperatures, and actuator motor current.

*A product of the A.P. Green Refractories Company

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After approximately 100 cycles of this type of operation, the motor current had increased slightly, and occasionally the over-torque limit switches would trip, actuating the Actuator Recycle System (ARS) which causes the actuator to reverse directions briefly, and then try to reclose. The test personnel were instructed to increase the torque limit switch setting slightly, which removed the problem, but slightly higher motor current readings continued. The torque limit switches had been deliberately set very low in order to make the ARS as sensitive as possible.

The test plugs in the valve ports were removed in order to observe the gate motion. This was done to determine if something was causing the gate to jam, thus causing the higher torque. No damage was found, but it was observed that the gate did not reach the fully open position. The CCC program manager was contacted, and instructions were given on restoring the proper setting on the actuator positioning limit switches.

During the testing at 600°F and 850°F, the seat leakage was observed to increase from the original values. Leakage was originally less than 50 SCFM at 1600 psi. When leakage exceeded 80 SCFM the test was terminated, with approximately 800 cycles of operation complete.

CCC personnel were present to assist in the disassembly and inspection of the valve. The test apparatus had all been removed prior to the arrival of the CCC people.

Visual inspection before disassembly revealed that the ceramic inlet seat was broken. Close examination of the outlet port revealed several "blisters" on the inside of the port, as sketched in Figure 4. The blisters were breaks in the ceramic coating used on both inlet and outlet ports as abrasion resistant linings. It is felt that the increased leakage measured at the end of testing was a result of cracking in the refractory lining which allowed flow to bypass the normal sealing components.

The valve was actuated several times, and it was observed that there was considerable lost motion at the beginning of each cycle (opening or closing), and that the gate did not

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go fully open, even though the stroke and actuator position controls were correctly set. There was a perceptible delay between the starting of the actuator motor and visible motion of the gate. The CCC program manager suspected that the gate had broken at the clamp area.

The valve was disassembled without incident. The gate proved to be broken as suspected. The broken inlet seat came out easily. The gate wear tiles were cracked in a non-functional area. This type of cracking has been observed before, and is reported in document FE-2355-42, "Internal Temperature Test Report, Lock Hopper Valve, Type III". The outlet seat, the ceramic spring, and the gate seal disk were undamaged.

DISCUSSION OF FAILURE

The most obvious failure was the cracked inlet seat. This cracking is felt to be a result of thermal stress caused by a higher temperature on the inside of the seat than on the outside. A similar test was performed at CCC (see FE-2355-42, as above) without cracking the inlet seat, at temperatures up to 950°F. The differences in the two tests is that the METC test supplied heat in the form of electric resistance heaters inside the valve with no flow. Temperatures were measured by thermocouples attached to the sides of the valve internal flow passages. The CCC test supplied heat in the form of hot air passing through the valve. The temperature was measured in the air stream as it entered the valve. Thus the METC test may have heated the valve more than the CCC test, even though CCC used higher temperatures, in theory. In a companion test at CCC, using the Type I, II, and IV valve configuration, cracking in the inlet seat occurred with only 130°F differential across the ceramic. The computed stresses from the Type III configuration are not significantly different from the Type I, II, and IV for the same temperature difference. The cracking can be said to be predictable at relatively low thermal gradients, and will eventually involve the outlet seat as well, and possibly the spring. This dire prediction can be overcome by providing better insulation for the ceramic parts. This observation is so important that a later section of this report will be dedicated to explaining the concepts involved.

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The cracking which occurred in the inlet seat, although very visible and easy to detect has no effect on the functioning of the valve. The inlet seat functions mainly as a guide and retainer for the ceramic spring. No sealing function is performed by the inlet seat.

The crack found in the gate clamp area is more serious. This component has been tested on numerous occasions (see FE-2355-21, "Component Development Test Report"). Ultimate tensile load testing showed repeated failures in the clamp area, with a reported failure load of 3725 pounds. It was speculated that the failure load would have been much higher, but a spherical washer was left out of the test apparatus, inducing bending into the gate. Since actual measure forces to move the gate are only 360 pounds, the design was felt to be sound, but follow-on testing was done to verify various design changes, and several specimens did fail in the clamp area at 1500 - 2000 pound loads. This was puzzling at first, since the clamp area has a very large cross section, with a calculated strength of 15 - 20,000 pounds. At length a simple fix was devised, as follows:

The failure was felt to be the result of high local stresses due to point loading between the gate and the steel clamp. With no ductility to redistribute the load, the gate failed in brittle fracture as soon as a single point load exceeded the tensile strength of the material. Once this was realized, it was obvious to provide a cushion between the clamp and the gate, and a single layer of ceramic paper of .030 inch thickness was used for this purpose. Testing showed a failure load of 8900 pounds, with failure occurring at the narrow "neck" between the ceramic disk and the edge of the gate, not in the clamp area. (See Appendix A). The problem was considered solved, and the ceramic paper was incorporated into the valve design.

The cracking observed after testing at METC is very similar to the earlier cracking during development testing. The ceramic paper was found to be loose and completely out of its intended area. Several possibilities exist: If the paper had been improperly installed (too loose, no clamping action?) it could have fallen out, permitting the high local loads which induce failure.

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If the paper were properly installed, the repeated cycles of actuation may have crushed the paper to the point that it fell out, permitting the high local loads. Or, the failure may be a cumulative result of the repeated load cycles (fatigue failure).

Several means of the reducing the likelihood of such failures suggest themselves. First of all, another material could be substituted for the ceramic paper (asbestos, fiberglass, graphoil). There are a number of resilient materials which could be used in the relatively cool area around the clamp. One might also use a solid ceramic gate. The first designs avoided this option due to the perceived difficulty in fabrication. This difficulty has been partly overcome and the solid ceramic gate is a reasonable alternative. In any case additional testing would be a worthwhile investment.

The other serious problem with the valve was internal leakage. The leakage measured initially is considered to be high, at 50 scfm. The increase in leakage is suspected to be caused by cracking in the refractory lining of the valve, possibly fatigue cracking aggravated by thermal stresses. The blisters noted inside the outlet port could have been flaking from within, caused by small leak paths inside the refractory. The test equipment had all been removed before the blisters were noticed, so there was no way to check for leakage at the blisters.

The use of refractory to retain pressure had been identified as questionable earlier, and modifications of the basic design had been studied.

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SUMMARY OF SIGNIFICANT TEST FAILURES AND CAUSES

- A. Inlet seat cracking was caused by thermal gradient through the radial thickness of the seat.
- B. Gate cracking in clamp area was caused by high local stresses due to poor load distribution (ceramic paper came out or was damaged) or by fatigue.
- C. Increased internal leakage was caused by internal cracking of the refractory lining, possibly aggravated by thermal stresses.

Other anomalous operation, such as slightly increased operating torque are not felt to be significant.

PROPOSED DESIGN CHANGES

A number of real and potential problems with the Type III Lock Hopper Valve were identified early in the manufacturing phase. The refractory concrete parts were fragile, and the method of construction made it difficult to retain the very close fits required for proper functioning of the valve. Several modifications to the fabrication tooling and procedures were made to facilitate the manufacture and assembly of the valves, but the basic design was kept since fabrication was well advanced. The assembly problems and solutions are documented in the monthly reports (FE-2355-1) and quarterly reports (FE-2355-2) submitted since October 1977 when the present program manager was assigned to the program.

A more fundamental concern was the use of refractory cement in a pressure retaining, load bearing role. Several accommodations were forced by the design. It became necessary to use high-strength refractory cements, with insulating properties being reduced to a secondary role. It was also deemed important to use a refractory with a good match to the thermal coefficient of expansion of the alumina ceramic, due to the composite construction method which was developed. The green-cast 94 material was selected based mainly on the above considerations. (It was learned later that only a very small shrinkage during curing could be tolerated).

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The strength of refractory remained suspect. The measured strength in bending tests was 1000 psi, $\pm$ 500 psi. But, applied loads were low, and earlier programs at Consolidated Controls gave some confidence in this method of construction.

The Type I, II, and IV design was actually changed to avoid some of the concerns expressed above, but the Type III valves were left alone, mainly due to the large amount of hardware already completed. A new design concept began to evolve, however, and several sketches were made and kept for future use. Some formal design work was begun in 1980, but was stopped at the direction of the DOE program manager. With the test results now available, the revised design is recommended for further study.

Basically, the revised design keeps the good features of the previous design, but removes some of the problem areas. The revised design is shown in Figure 5. The important difference from the previous design is the use of two high density alumina ceramic housings to retain pressure and to transfer loads to the steel body. With no structural function to perform, the castable lining can now be made of light-weight insulating refractory. The difference is profound. With good insulation (10 times more insulation ability) the thermal gradient through the ceramic parts is greatly reduced. The heat loss in the valve is reduced and the temperature of the steel valve body is reduced. By making the insulation in layers (or, as has been suggested elsewhere, in a fibrous material) cracking is minimized, and the effects of cracking in the insulation is harmless. This simple modification solves two of the three problems encountered in the static test, the cracked inlet seat (and potential for other components), and the damaged refractory lining. The gate cracking is relatively separate, and should be attacked by investigating better cushioning between the gate and clamp, or by a solid ceramic gate. A solid ceramic gate could also be smaller, and hence easier to fabricate, and the extra space so obtained could be used for additional insulation, further reducing the thermal gradients encountered.

When one begins considering materials on the basis of insulating value rather than strength or thermal coefficient of expansion, there is an enormous increase in the number of materials avail-

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available. Castable refractories have already been mentioned, along with fibrous materials. Another candidate material is fused silica, which is possibly the best material for the inner insulations. The flow channels will still need to be lined with abrasion resistant material. The selection can be from a large number of materials, including dense alumina ceramic, high-density castable refractory (green-cast 94), or dense fused silica. The last material may be suspect at temperatures above 2000°F as it tends to recrystallize and lose its volumetric stability at around 2100°F.

In short, the simple modification proposed offers substantial promise of performance improvement. CCC whole-heartedly recommends that at least one valve be modified as proposed and tested.

SUMMARY

The problems encountered in static testing the CCC Type III valve are not viewed as major "show-stoppers". The CCC program manager has been very open in discussing the potential for this type of problem, well before their actual occurrence, and a sensible, workable fix has been prepared, based on better utilization of the material properties of materials which are readily available. It is our firm conviction that this line of approach should be followed up, and could have been initiated some time ago, with good possibilities for success.

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TYPICAL LOCKHOPPER VALVE APPLICATIONS

VALVE TYPE	MAX TEMP (°F)	MAX PRESS (PSIG)	DESCRIPTION	COMMENT
TYPE I	350	1,600	FEED SYSTEMS -INLET TO LOADING OR INJECTION LOCKHOPPER	TYPE I, II, & III VALVES ARE TO WORK WITH ANY GRADE OF COAL AVAILABLE IN THE UNITED STATES, OR WITH DOLOMITE, OR COAL/DOLOMITE MIXTURES WITH OR WITHOUT PRESSURIZING GAS
TYPE II	850	1,600	FEED SYSTEMS -INLET TO REACTOR OR GASIFIER	
TYPE III	2,000	1,600	CHAR & ASH REMOVAL OUTLET OF REACTOR OR GASIFIER	
TYPE IV	600	1,600	SLURRY DISCHARGE VALVES OUTLET OF REACTOR OR GASIFIER	TYPE IV VALVES ARE TO WORK WITH MIXTURES OF COAL, CHAR, ASH, & DOLOMITE PROCES PRODUCTS IN ALIQUID SLURRY

FIGURE I

TYPICAL LOCK HOPPER VALVE OPERATING CONDITIONS

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TYPE III VALVE (2000°F)

FIGURE 2

OVERALL ARRANGEMENT OF TYPE III VALVE

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FIGURE 3

DETAILS OF CERAMIC CONSTRUCTION OF TYPE III VALVE

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FIGURE 4

SKETCH OF BLISTERS FOUND IN OUTLET HOUSING

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FIGURE 5

PROPOSED REVISED DESIGN

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APPENDIX A

RESULTS OF GATE ULTIMATE LOAD TESTS