Investigation into the Causes of Pressure Relief Valve Failure

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Abstract-- This paper describes the preliminary investigation of a research project that aimed to test and identify the causes of pressure relief valve failure. A test rig suitable for testing of relief valves was designed, constructed, and tested. The purpose of the data collected by testing is intended to support the alternative path to determine the service life of relief valves following their removal from the system prior to their replace or disposal. Design, maintenance and operating changes resulting from data and failure analysis can provide significant reliability improvements and reduced costs over the lifetime of a valve.

Keywords—Erosion pits, Poppet, Valve seat, Pressure Relief Valve, Leakage.

I. INTRODUCTION

Understanding and predicting the relationship between pressure drop and flow rate through orifices is essential for the design and evaluation of fluid power and flow control devices. Hydraulic valves differ from process control valves in application and design. Hydraulic valves are typically used for controlling pressures are of the quick opening type of characteristics. Quick opening valves utilize plugs shaped in the form of a truncated cone with relatively large clearances between the plug and the seat. Pressure relief valve test intervals may be safely extended when supported by quality test data, statistical tools, and failure analysis.

The ability to understand and manage the performance of hydraulic control valves is important in many automatic and manual industrial processes. The flow inside the poppet valve is a complex process which is strongly dependent on the details of the valve geometry, the fluid properties and the operating conditions. Separation and re-attachment of jets can have a profound effect on the flow pressure and force characteristics as well as influencing the susceptibility to cavitations.

A poppet valve seating-type valve in which the moving element or poppet, usually spherical or conical shape, moves in a direction perpendicular to its seat. Because of the several advantages that are associated with poppet valves such as ease of manufacture, minimum leakage, and insensitivity to clogging by dirt particles, poppet’s have been used for as pressure regulators and relief valves. The operation of this type of valve is quite simple. The fluid pressure counterbalances the spring force and allows fluid escape through the annular passage way between the poppet and the seat.

Till now, two approaches are usually adopted to study the performance of a spring loaded PRV. One is the experimental study. Many researchers have experimented and analyzed spring loaded PRVs for the fluid characteristics, operating parameters, and the coefficients such as discharge coefficient and pressure loss coefficient. From the viewpoint of practical application, this method is more reliable and suitable, since the real situations are usually simulated in the experiments. But on the other hand, this method is very expensive in time, manpower and facilities. Hence, with the development of computer and numerical method, more and more researchers started to use computer simulation to investigate.

As pointed in , the poppet flow is not easily suited to classical mathematical analysis. The relative simple geometry, Fig. 1a, produces a very complicated viscous flow field, which can be realistically investigated only in the industry hydraulic systems valves are often used to control the systems. In case of a complex system with many hydraulic valves, it will take a lot of time to localize a defect valve in the system, and sometime a defect valve could result in large damage of the system. To find this defect on the valve before it will damage on the system would be very helpful.

Fig.1. Pressure Relief Valve cut section

II. DESCRIPTION OF A SPRING LOADED PRV

The simplified representation of the spring loaded PRV studied is shown in Fig.2.

Fig.2. Direct operated pressure relief valve (1- Valve housing; 2 - Spring; 3- Adjusting screw ; 4-Spring retainer; 5 – Poppet; P - inlet; T - outlet)
The pressure setting of the valve is achieved via compressing the spring a given length. When the pressure at the upstream is bigger than the setting pressure, the poppet will be lifted due to the break of the force balance previously by the force of flowing fluid acting on the poppet.

The opened gap between the valve seat and poppet relieves some flow to the outlet. The relieved flow increased the lift force suddenly, which cause the valve poppet open more and suddenly, when the major flow enter the chamber, the build-up back pressure becomes bigger and reduces the total lift force induced by the fluid. Under the total effect of flowing fluid and spring, the valve poppet will achieve its steady position gradually after a period of fluctuation.

III. RELIEF VALVE FAILURES

Hydraulic valves are precision-made and must be very accurate in controlling a fluid pressure, direction, and volume within a hydraulic system. Contaminants, such as dirt, in the oil, geometry clearances and wrong selection are the major problems in valve failures. Small amounts of dirt, lint, rust, or sludge and misalignment of valve parts can cause annoying malfunctions and extensively damage valve parts. Such material will cause a valve to stick, plug small openings, or abrade the mating surfaces until a valve leaks.

Investigation Into the valve failure due to erosion

Present understanding of the mechanism of erosion is far from complete, because it is a complex and highly localized phenomenon that involves the interaction of hydrodynamical, mechanical, metallurgical, and chemical effects. Understanding of such complex phenomenon requires a full clarification of the erosion mechanism and controlling parameters inherent to it, so that erosion can be prevented, or at least be reduced. This cannot be done without full information and collection of massive data under different conditions.

From the literature survey a consensus has developed that material removal in multiple-impact situations cavitation erosion, liquid-droplet erosion, and of solid-particle erosion is not a result of single impulses or impacts. It clearly showed that the predominant failure mode in material erosion was fatigue. This damage accumulates over thousands of impacts before a particle is dislodged.

Erosion is the material removal of a solid surface caused by impact of fluid forces. The degree of the erosion depends on various factors such as intensity of cavitation, geometry of cavitation jet, pressure and temperature in a system, properties of fluid such as viscosity and density, and material properties such as hardness, work hardening capability, and geometry.

Fig. 3. (White circle shows worn surfaces i.e., erosion pits, deformed groove on the Popplet and valve seat)

Appearance of worn surfaces

It is observed that many of the valves used in the range of one to two years have the wear scars achieved on the valve seating faces appeared uneven. Observation of the seating faces of both the poppet and valve seat revealed the presence of erosion pits and groove. The unevenness of the wear scars was caused by non-uniform contact between the valve and seat insert.

From the previous studies, it is known that the initial stage of the erosion, i.e., the incubation period, is of paramount importance in understanding the basic mechanism of the erosion, and pit formation is one of the characteristics of this period. Pit formation is generally acknowledged to be a complex process. The shape, depth, and appearance of pits will depend on the amount of forces acting on the poppet and valve seat region, however, pit formation is still the subject of debate among many investigators, partially because the test conditions are somewhat different from each other. In addition, the effects of these pits on erosion or development of erosion are still uncertain.

IV. TROUBLESHOOTING THE RELIEF VALVES

Listed below are the areas that you can troubleshoot the relief valves:

- If low or erratic pressure occurs for the sake of troubleshooting, the following items must be considered.
  - Valve adjustment is incorrect.
  - Dirt, chip, or burrs may cause the valve partially open.
  - Poppets or seats may be worned or damaged.
  - Valve piston in the main body may be sticked.
  - Selection of spring is wrong
  - Spring ends may be damaged.
  - Valve in the body may be cocked.
  - Orifice or balance hold may be blocked.

- If relief valve has no pressure, the following items must be considered.
  - Orifice or balance hole may be plugged.
  - Poppet does not seat.
  - Valve may have a loose fit.
  - Spring may be broken.
Dirt, chip, or burrs may cause the valve partially open.

- Poppet or seat may be worned or damaged.
- Valve in the body may be cocked.

If excessive noise occurs consider the following items:

- Oil viscosity may be too high.
- Poppet or seat may be faulty or worned.
- Line pressure may have an excessive return.
- Pressure setting is too close to that of another valve in the circuit.
- Spring may be broken.

If adjustment of the relief valve cannot be achieved properly, consider the following items:

- Spring may be broken.
- Fatigue for spring material may come across.
- Improper spring may have been used.
- Drain line in system may be restricted.

V. PRESSURE RELIEF VALVE CYCLIC TEST RIG

To investigate the valve fatigue failure conducted cyclic test on the designed valve test rig. We found from these cyclic tests valve failure depends mainly on the valve design, fluid, fluid contamination and flow characteristics.

In this study, we focus on the details of the flow fluctuations around the poppet for various pressure drop. Erosion pits and their effects on erosion progression were investigated in detail for direct acting Pressure Relief Valve (DPRV06) and by means of designed cyclic valve test rig. There are mainly two kinds of poppet and valve seat damages observed from the rejected valves. These are erosion pits, deformed groove on the poppet and valve seat were found on the valve specimen surfaces.

Long duration tests are performed in order to determine experimentally the incubation time and the mean depth of penetration rate. These effects are generally due to an interaction between the cavitating flow and the walls via, for instance, changes in roughness or wall shape induced by the wear itself. Flow conditions can also have a dramatic effect on wear rates and patterns. Using our test facilities, the effect of variations in flow conditions such as pressure or overall flow rate can be tested by observing the leakage flow.

Developed manifold for pressure relief valve mounting on the valve test rig. Parameters included for test are cycles, geometry, oil temperature and material. Valve seat and poppet materials characteristic of those currently used in DPRV06 applications were selected for use in the tests. The geometries of the valve seat and poppet are shown in Fig. Both the poppet and valve seat materials are different with different hardness.

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Hardness</th>
<th>Hardening</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poppet</td>
<td>SAE8620</td>
<td>RC 42-45</td>
<td>Through</td>
<td>3.410 gm</td>
</tr>
<tr>
<td>Valve Seat</td>
<td>EN-19</td>
<td>RC 58-60</td>
<td>Case</td>
<td>26.040 gm</td>
</tr>
</tbody>
</table>

Bench test work designed to investigate valve and seat wear and isolate critical parameters, the data from which could be used to develop a model to predict valve recession.

The aims of the cyclic bench test work were to:

1. Investigate the wear mechanisms occurring in the valve mainly on the poppet and valve seat.
2. Study the effect of valve wear in the hydraulic circuit.
3. Effect of fluid temperature on the valve elements.
4. Quantify the effect of poppet and valve seat contact.

To develop procedures for the inspections and testing of pressure relief valves that follow “good engineering practices.” The good engineering practices identified included conducting leakage test and visual inspection of pressure relief valves when removed from service.
The test rig was designed and tested flawlessly to determine at what pressure the removed relief valve would have actuated. The next step is to use this data to determine whether or not the relief valve “passed” or “failed.” The data generated from this test procedure can be used with a statistical analysis to justify changing the service life of the pressure relief valves in similar service to insure safe operation.

Its installation at that location does not affect the reading since the pressure of interest is the valve “starts-to-leak” and/or “crack pressure,” both of which are low flow conditions. As such, the pressure read off the gauge in this location is virtually identical to the relief device inlet pressure at the point of relief valve operation.

The relief valves tested included a mix of new and used valves. We choose used relief valves from a variety of customers as well as locations throughout the plants where the project being carried out. The range of locations allowed us to test the “condition report” requirements of the procedure in order to see if the form included within the test procedure adequately captured the necessary information.

Relief Valve Test Observations

We tested five (5) used relief valves and five (5) new relief valves. Since the purpose of the tests was to validate the method, no archival “data” on the tested relief valves was generated. The pressure relief valves were put through the originally proposed procedure to see if the set pressure could reliably be determined with the start-to-leak test.
VI. RESULTS AND DISCUSSIONS

The outcome of this effort was focused on determining whether the test rig was adequate in size and function, and that the test procedure is capable of providing data that can support downstream statistical analysis of relief valve mechanical integrity (service life).

The valve seat, poppet wear problem involves two distinct mechanisms: impact of the poppet on the valve seat on valve closure and sliding of the poppet on the valve seat under the action of the system pressure.

Depending, however, on the accuracy of the poppet and the valve seat machining, it is conceivable that such misalignment may occur in valve and, therefore, be a source of valve recession. When a component reliability program is in place to verify relief valve functionality and longevity by history, testing, disassembly and inspection, and periodic statistical review of these activities, relief valves may be replaced at any interval justified by the findings of such a program. In the absence of such a program, each relief valve shall be replaced at the frequency recommended by the relief valve manufacturer. In the absence of both a component reliability program and manufacturers’ recommendations, relief valves shall be replaced every five years if not indicated earlier at annual inspection.

Having analysed the root causes of the valve failure and considered the implications for valve design and seat and poppet materials, it is decided to investigate the potential for reducing valve recession by improving the existing design.

VII. CONCLUSION

Stating the root cause of valve recession is difficult. Each valve recession problem will have its own unique set of operating parameters, design features, and material combinations. The investigation, however, has clearly shown that:

A successful design of poppet valves requires a thorough analysis of both velocity and pressure fields, with the aim of improving the poppet/seat geometry.

1. Systematic observations of the feature of erosion pits and the groove showed that the predominant failure was a fatigue process. In order to detect erosion damage of the closure member or possible blockage in the valve body, it is necessary in addition to measure the pressure over the valve and to obtain data of the volume flow through the valve. This data can best be obtained through a data transfer bus from the measurement sensors.

2. Material choice is clearly critical in addressing valve wear problems. In deciding which material combination to use, consideration should be given to deciding which is more preferable: greater valve seat wear or greater poppet wear.

Clearly, replacing poppet is less costly than replacing valve seat. Therefore, work needs to be focused on reducing poppet and valve seat wear at an acceptable level. Ultimately, however, it would be preferable not to have to replace either and to reduce the adjustment required on valve clearances, as a result of recession, to an absolute minimum. In selecting materials, consideration must be given to the relative resistance required for wear.

3. The bench test apparatus provides a valid physical simulation of the wear of both poppet and valve seat in the pressure relief valve. An obvious possible upgrade to the test rig would be to integrate a pressure transducer and computer data acquisition program.

4. Wear may increases with valve closing velocity, system pressure, and misalignment of the poppet, valve seat and spring retainer.

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