MONITORING THE CONDITION OF LOADED MODERN WATER HYDRAULIC AXIAL PISTON MOTOR AND CYLINDER

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ABSTRACT

Recent advancement in technology has produced materials that can withstand highly corrosive environment and lubrication-free materials for water hydraulic components. With precision machining becoming possible, very close tolerances can now be achieved to reduce internal leakage due to the low viscosity of water. Many industries are slowly but steadily turning to water hydraulic systems to replace their oil hydraulic systems. The use of water hydraulic systems will increase in future as new applications are found for this technology. As with all systems, the increasing use of water hydraulic systems by more industries will result in the need to monitor and maintain the systems.

This paper is concerned with the condition monitoring and fault diagnosis of loaded modern water hydraulic cylinder and axial piston motor. LabVIEW software was used for data acquisition and processing. It provides a graphical programming environment that integrates data acquisition, analysis and presentation in one system for effective analysis. Likely real-life faults were simulated on the actuator's internal components. Some results such as the vibration signatures and amplitude spectra of the water hydraulic actuators under different operating conditions of simulated loads and speeds are presented and discussed. The results show that there is a distinctive variation in vibration signals, flow rate and average stroking duration with increase in loads for both actuators. The actuators were also operated to capture their unique vibration signals in their faulty states and the results compared with reference signatures of the same actuators when they were in their new or healthy states. The results imply that LabVIEW software can be written to set warning levels and trigger an alarm when a fault is impending.

Keywords: Fault diagnosis, water hydraulic system

INTRODUCTION

Water hydraulics was invented as early as 200 B.C [1]. In the early part of the last century, it was overtaken by oil hydraulics in terms of research effort and industrial applications. Compared to oil hydraulics, the advantages of using water medium are as follows [2]: 1) Water is environmentally-friendly and non-toxic; 2) Water is readily available and cost-effective; 3) Thermal conductivity of water is 4-5 times that of mineral oil and water systems tend to require less cooling capacity; 4) Water contains much less air in solution which can affect the rigidity of hydraulic systems. Recent advancement in technology and design has sparked new interest for the application of water hydraulics. Although current related applications and research works have been limited to a few industries and research institutions, its potential remains great.

As water hydraulics systems are expensive compared to their oil counterparts, the traditional practice of indiscriminately replacing components at regular intervals to prevent unexpected failure cannot be employed as this will incur high costs. The other extreme practice of running the system until its components break down completely before replacement is also unacceptable because by then, the quality of the products it manufactures could have been affected considerably and rejects would have increased due to the faulty system. Since water hydraulic system will form an integral part of a larger system, the practice of dismantling the suspected trouble component(s) will result in total system down time and consequently low yield and high costs. The best approach is to carry out on-line condition monitoring and fault diagnosis as production will not be affected during monitoring. This will enable potential component or system failure to be detected and action taken to remedy the situation.

EXPERIMENTAL SYSTEM ARCHITECTURE

The modern water hydraulic system installed in the School of Mechanical and Production Engineering, Nanyang Technological University was acquired from a European manufacturer [3]. The system comprised many components ranging from the water hydraulic test rig to the data acquisition board. The hardware design was linked to the software which has its own elaborated architecture too. The system setup comprised a water hydraulic system, a loading structure for the cylinder and the motor, several sensors, a signal conditioner, National Instrument's AT-MIO-16L-9 data acquisition card, PII 233MHz PC installed with LabVIEW as the interfacing software. The dead weights were fabricated with 40 pieces of 10kg for the cylinder loading. The weights were mounted incrementally on the water hydraulic cylinder which is set in the vertical position. Similarly, the water hydraulic motor is loaded by coupling it to another load motor, with the loading adjusted by throttling the load motor of the oil hydraulic line.

In the research, the vibration signals were amplified by the charge amplifier and sent to the signal conditioner to filter off unwanted noise. The data acquisition board samples, holds, reads and translates the signal with the aid of LabVIEW.

Fig. 1 shows the overall system schematic architecture flow for condition monitoring. As mentioned, the vibration signals were firstly read by the accelerometer and then were amplified and conditioned before processing by LabVIEW. The pressure sensors, flowmeters, linear sensor and a temperature sensor were all powered by external DC supply. Signals from the linear sensor and temperature sensor were sent to the analog filters and then acquired by LabVIEW. The pressure sensor and flowmeters have their own separate display unit. However, their signals can be connected to the software as well.

The software architecture is another equally important aspect of the research and this is where signals from the hardware will converge, conditioned, sampled, displayed and analyzed. Data acquisition architecture is vital for the credibility of results obtained. Without a proper design, signals obtained may carry aliasing, noise or erroneous scaling. Hence, it is of utmost importance to develop a reliable yet lean programme to correctly exposite the results.

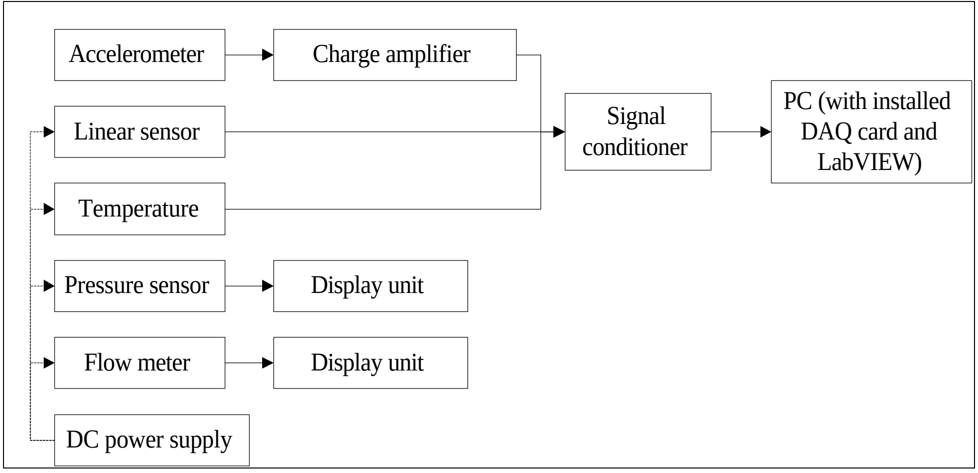

Fig. 1 Schematic hardware architectural design.

A complete algorithm was written to read and condition the incoming signal to eventually display it on the monitor. There are several programs written for different executions. The typical hierarchical execution of the software is used for monitoring vibration. The software includes a main program and several sub-programs which are called upon by the main program, by means of pointers similar to C language.

The algorithm was designed to allow a layman operator to handle the software, giving necessary vital details and offer various adjustable parameters. The block diagram can be schematically represented in Fig. 2. The AI Acquire Waveform acquires the specified number of samples at the specified scan rate and returns all the data acquired in scaled data units. It is the first interface between hardware and software that provides vital links to the acquired signals.

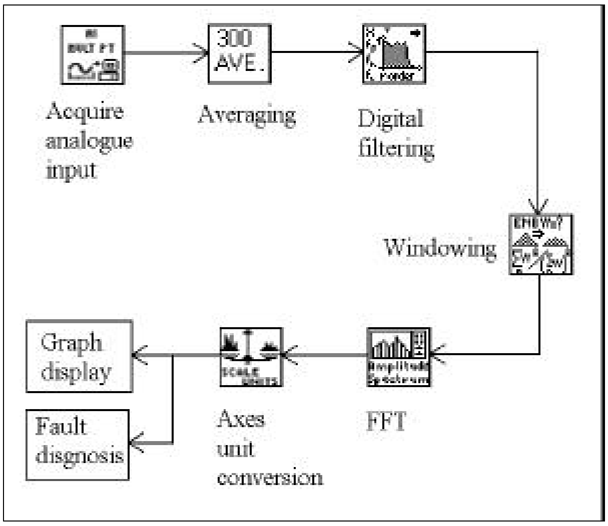

Fig. 2 Schematic diagram of software algorithm.

CONDITION MONITORING OF TWO HYDRAULIC ACTUATORS

Two hydraulic actuators are studied for their performance and response to impending faults. They are water hydraulic cylinder and reciprocating motor. Since most studies revolved around the internal components of the actuators, it is important to understand the working principle of the parts and perceive how the mechanisms work together harmoniously.

Particular interest centers around the marvelous technology on how closer tolerances have been achieved in water hydraulics cylinder. Fig. 3 shows the internal components of the cylinder. Taking a closer look at the piston(in Fig. 4), the cylinder has intelligently overcome this feat by having a series of felt seals together with the Buna-N rubber seal to achieve minimal internal leakage. The felt seal is actually moulded from hardened rubber intertwined with a web of threads. It can double as a cleaning agent, grazing the bore each time the piston moves. The reinforced plastic is used as a last-line support when the series of seals started to wear. This is to prevent the metallic abrasion between the piston and the internal bore, which is very damaging to the entire cylinder. When wearing is about to reach the reinforced plastic, it is time to replace the seals. The piston is screwed on the rod instead of being wielded or manufactured as a piece. This modularity allows changing of parts since the piston will experience the most wear in a cylinder.

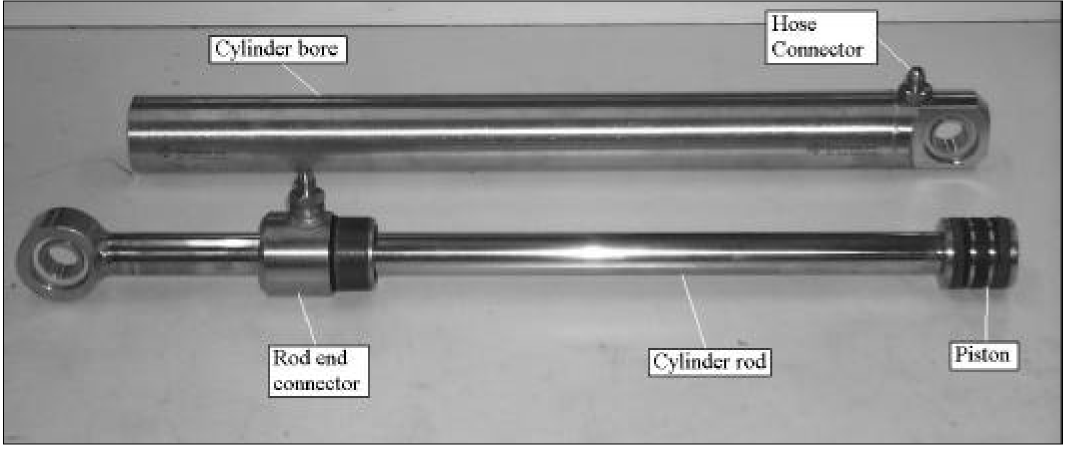

Fig. 3 Internal components of the water hydraulic cylinder.

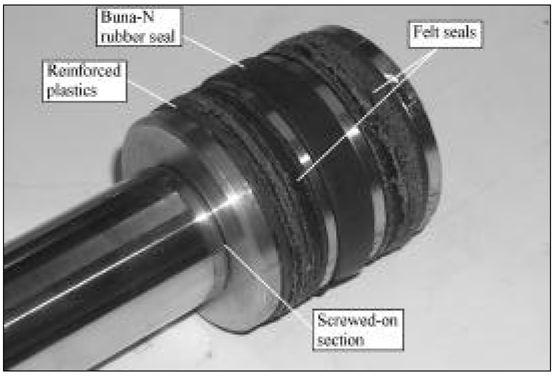

Fig. 4 Close-up view of water hydraulic cylinder piston.

The hydraulic reciprocating motor is much more complicated than the cylinder as it contains more internal components than the cylinder. Fig. 5 shows the internal components of the motor.

The motor has eliminated the need for external lubrication by ingeniously designing some discharge cavities to maintain water as its sole lubricator. Interestingly, the motor has done away with the ball bearing technology. Instead, it replaces a reinforced plastic sheath that supports the motor shaft. This allows easier changing when wearing occur, rather than replacing the conventional ball bearing. The concept is that it is impossible to reduce wear to nil in any actuator, so another approach will be to design some material that can be easily replaced after it had worn out. This material must be able to sustain high load in the hydrodynamic and static films which will occur between the moving parts, and can exhibit acceptable low dry friction and rate of wear to reduce mechanical losses.

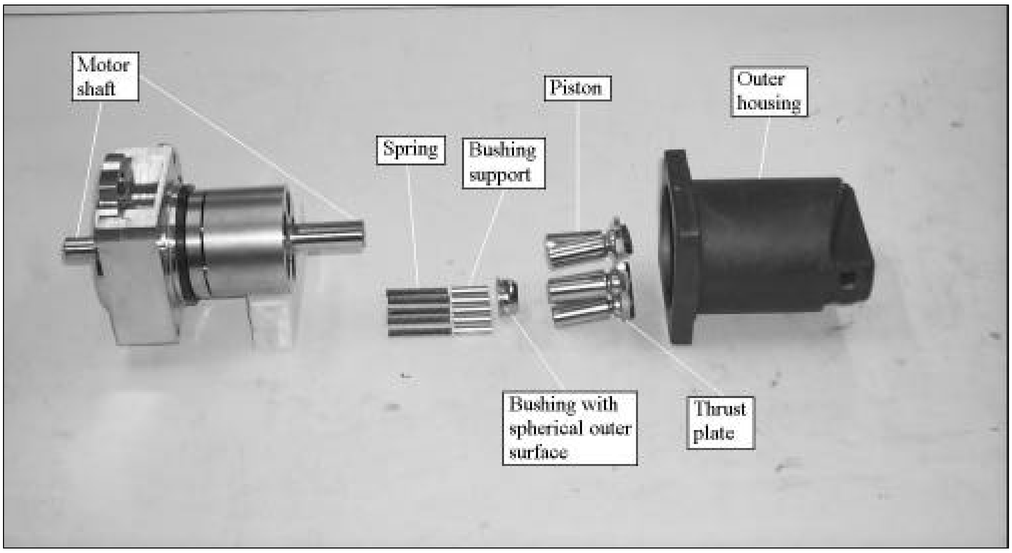

Fig. 5 Internal components of the water hydraulic reciprocating motor.

RESULTS AND DISCUSSION

Two common industrial actuators, hydraulic cylinder and reciprocating motor, were investigated with loadings added in steps to observe their signatures. The investigation of condition monitoring and fault diagnosis includes piston/rod seal wear of the cylinder and capstan/slipper shoes wear of the motor. Elaborated hardware architecture was introduced to the experiment. There are several sensors installed to measure the trends of the actuator condition. They are accelerometer, pressure sensor, flow meter, linear sensor and temperature sensor. Vibrational energies, flow response and linear actuating stroke duration were the only variables which can be controlled for condition trending purpose. The software console was successfully written using LabVIEW and various signatures were presented in the experimental records.

The analyses indicated that for the hydraulic cylinder, with more piston seal wear, an increase in dBVrms was observed due to the rattling effect of the piston as it extends and retracts (Fig. 6). Rod seal wear showed a trough response for average stroke duration (Fig. 7). The friction caused by interference fit of the rod seal attributed to this. The hydraulic motor showed an increase in flow power spectrum with increasing wear when the slipper is worn because of the slipper lubrication design (Fig. 8). However, capstan wear showed a general flat response in the flow trending peak which suggested that capstan wear does not really affect the motor performance (Fig. 9).

CONCLUSION

From studying signals of water hydraulic actuators in faulty and healthy states under different operating conditions of simulated loads and speeds, we get the result that there is a distinctive variation in vibration signals, flow rate and average stroking duration for both actuators in healthy and faulty states with increase in loads. The result implies that LabVIEW software can be written to set warning levels and trigger an alarm when a fault is impending.

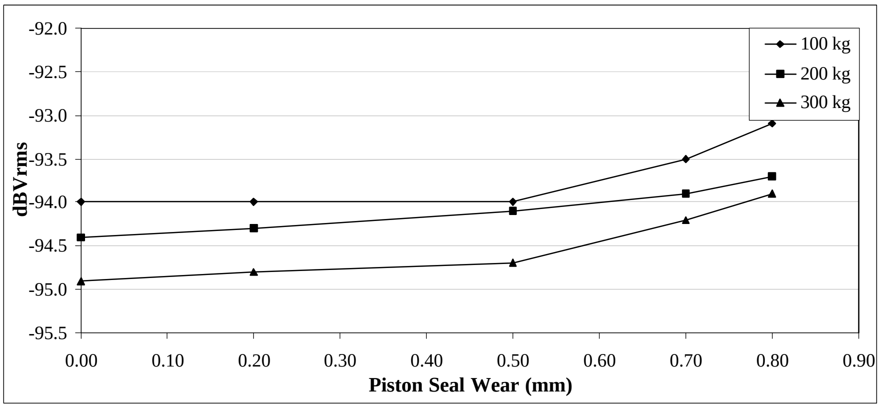

Fig. 6 *dBVrms* against piston seal wear of the cylinder for various loadings.

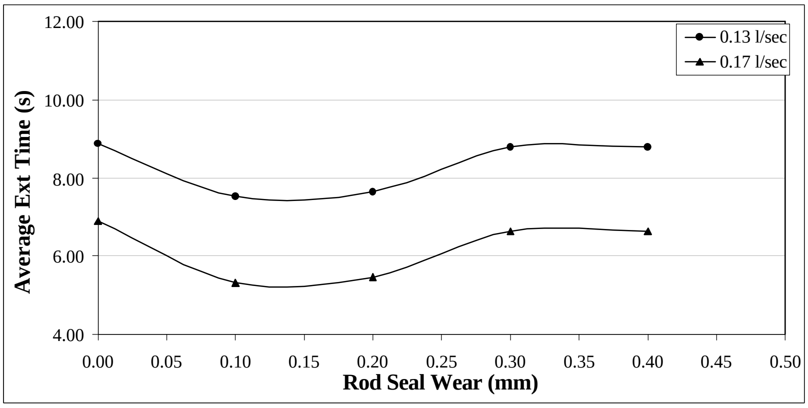

Fig. 7 Average extending duration against rod seal wear of the cylinder for two flow rates.

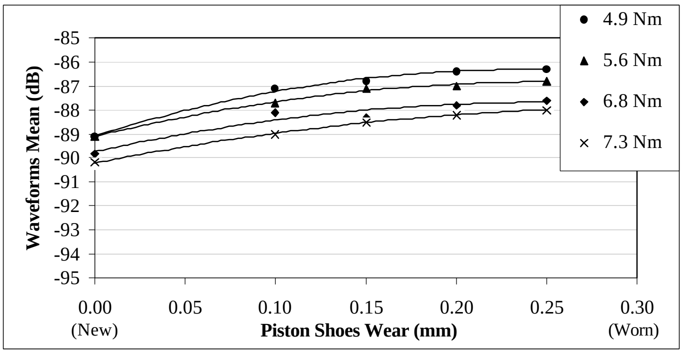

Fig. 8 Waveforms Mean against Piston Shoes Wear of the motor for inlet flow at 0.11 l/sec.

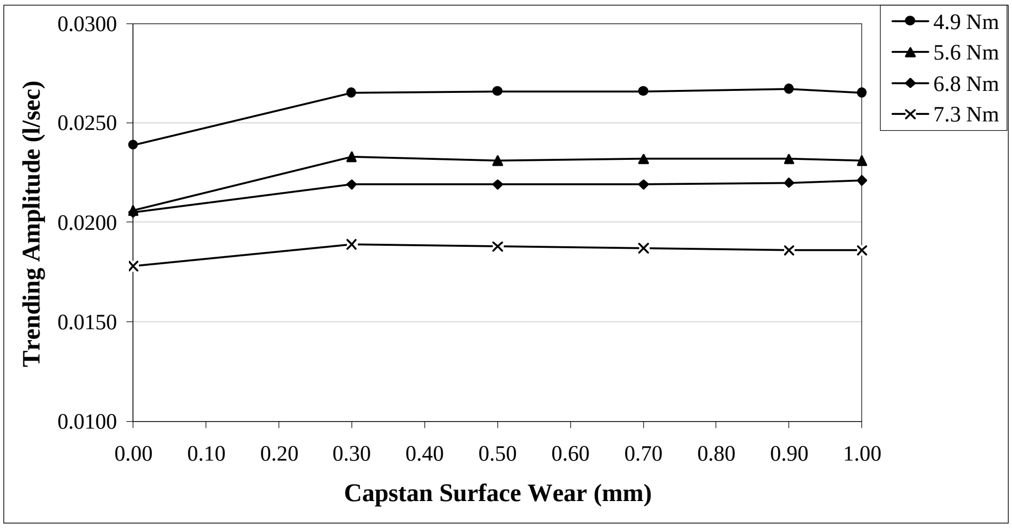

Fig. 9 Flow trending amplitude against capstan surface wear of the motor at inlet flow.

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