From reliable sensors to cylinder intelligence

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Abstract

Reliability of a piston rod position measurement system is key when applied to large hydraulic cylinders. This and other requirements lead to the development of the CIMS (Cylinder Integrated Measurement System), a contactless and highly accurate system that uses the Hall effect to detect an encoded piston rod. To eliminate deviations caused by mechanical tolerances, temperature and air gap variations etc., the raw signals are filtered and compensated.

Its functionality has been extended by making statistical data available, based on the values measured. These include the number of strokes, cumulative stroke length, stroke length distribution, maximum velocity and acceleration, temperature classification and extreme temperatures. Assessment of these data enables the user to optimize his application. Comparison to historic data can give input to the preventive maintenance plan to reduce (unforeseeable) system downtime and to increase the system reliability.

This development resulted into the CIMSmart. It is a significant step towards cylinder intelligence.

KEYWORDS: Position measurement, hydraulic cylinder, smart sensor

1. Introduction

Applications where (large) hydraulic cylinders are used often require a position signal in order to be able to control, or at least check the variable distance between the two mounting points of the cylinder. The systems that can generate such a position signal can be based on various physical principles, such as conversion of a linear movement to an angular movement for a draw wire sensor /1/, laser interferometry /2/, ultrasound /3/, and microwave /4/. Besides these, there are methods that use some form of piston rod encoding, which can be either absolute /5/ or incremental sensors /6/. Especially for large hydraulic cylinders, with stroke lengths over 10m, this type of sensor is generally characterized by a high accuracy position signal, independent of the stroke length.

1.1. Incremental piston rod encoding

One way to encode the piston rod is by turning a trapezium-like profile in the ferromagnetic steel rod on a lathe. This profile is coated subsequently using a non-magnetic or low magnetic coating material. Most of these coating processes will result into a more or less uniform coating thickness over the trapezium-like profile (see **Figure 1**). Consequently, the coated land-areas (the areas between the grooves) need to be removed afterwards in order to obtain a smooth piston rod surface (see **Figure 2**). This implies, of course, that the coating thickness needs to be higher than the depth of the groove of the trapezium-like profile.

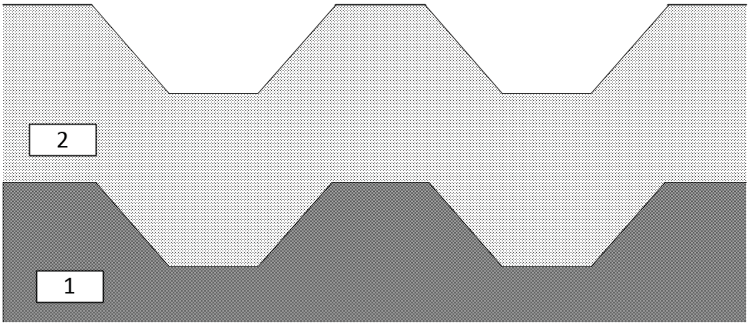

Figure 1: Trapezium profiled rod surface (1) with uniform coating (2)

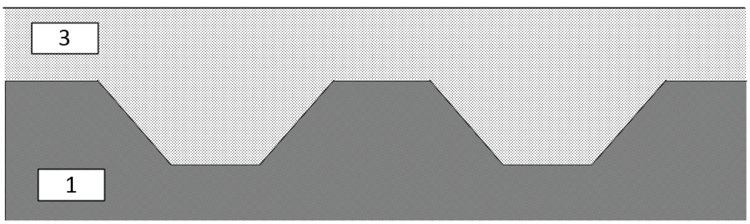

Figure 2: Trapezium profile rod (1) with reworked smooth surface (3)

1.2. Conversion of the piston rod encoding

A method to convert the piston rod encoding to an incremental position signal is found in /6/. A magnetic field is generated, either by an electromagnet or a permanent magnet. When placed near the encoded rod, this field is influenced by the presence of the trapezium-like profile. One could choose for a series of magnetic field triggered switches along the groove pattern to determine the position of the rod with an accuracy, limited to the mutual distance between these switches.

However, it was found that an approximate sinusoid signal can be generated by placing e.g. a Hall-effect sensor between the magnet and the rod, where the approximation depends on the exact design of the trapezium-like profile. When two of these sensors are placed between the magnet and the rod at a mutual distance, equal to the pitch of the profile plus or minus ¼ of this pitch, the sensors generate signals, close to a sine and a cosine. Thus, the phase angle can be determined, which can be converted into an accurate position within a single trapezium-like profile. As the fluctuation of the Hall effect sensor due to the moving groove pattern is in itself is limited, the concept of a differential Hall effect sensor is preferred. This differential sensor consists basically of two single Hall effect sensors, of which the signals are subtracted from each other. When placing these single sensors ¼ pitch of the groove pattern apart, the signal of the differential sensor is offset compensated. Air gap variations, i.e. variation of the distance between the rod and the Hall effect sensors, as a result of e.g. external moments bending the rod, can thus be compensated for.

1.3. Signal processing and error correction

In general, processing power is required to post-process the output signal of Hall effect sensors, but also to convert their output signals into some kind of analogue or digital position signal. As Hall effect sensors generally suffer from temperature drift, a temperature compensation algorithm is required. A separate temperature sensor can be used as an input for this algorithm. Other influences that require compensation are the exact relative positions and angles of the rod, the sensors and the magnet. These influences can be assessed during the initial movement over a single pitch after installation of the CIMS in the cylinder as, in principle, two sinusoidal signals are to be generated with a 90deg phase shift.

1.4. CIMS

The CIMS (Cylinder Integrated Measuring System) is the name of a contactless sensor that is based on the principles as described above. It contains a permanent magnet for generating a magnetic field, four Hall effect sensors, a processing unit for signal processing and conversion, and local storage to store the result of self-diagnosis functions. The processing unit converts the position signal into a RS422 /7/ differential signal. The diagnostic information can be read through a RS485 /8/ connection using the MODBUS protocol /9/, /10/.

2. CIMSmart

2.1. Application monitoring versus condition monitoring

Condition monitoring is important for any product with a certain complexity that has requirements on uptime. For condition monitoring to be successful, it is important to know relevant failure mechanisms of the product in detail and to have sensors in place to detect the early signs of the various failure modes. Mathematical modeling combined with physical testing can be used to determine the right quantities to measure and to find out the optimum sensor position in the product. Alternatively, using an empirical approach, one could log the signals of existing or dedicated sensors and through mathematical analysis determine the deviations from the normal operation modes, determined from these signals /11/. These deviations may indicate wear and/or predict failure of the product.

Application monitoring intends to store typical process data and process incidents. The difference with the empirical condition monitoring method mentioned above is the absence of advanced mathematical analysis. Instead, conventional SPC methods are usually applied. These methods can be found in commercially available data logging systems.

2.2. Position based key figures

The position sensor described in section 1.4 has the principle requirements for application monitoring on board. It continuously measures position and temperature, is fitted with a processing unit, has a data storage possibility, and has an interface to access collected data. Thus, it is possible to collect information about the use of the (large) hydraulic cylinder fitted with the CIMS. Implemented properties derived from position and temperature signals are discussed in the following sections.

2.2.1. Number of strokes

Of course, this is no more than a simple cycle counter that indicates to what extent the application has been in actual use. But it is also an indicator for a specific wear mechanism. Each time the cylinder rod starts to move, the fluid layer between piston rod and sealing elements needs to be built up. During this startup phase lubrication is sub-optimal, indicating increased friction and consequently wear of the sealing elements.

Once the life time of these elements in the application has been determined in practice, the number of strokes can be used as a simple first means for condition monitoring.

2.2.2. Total travelled distance

The total travelled distance simply sums the length of each stroke. For cylinders that make identical movements each cycle, this contains no new information if the number of strokes and the fixed stroke length are given. But when classed in time intervals, it indicates the actual use of the cylinder in time. For cylinders that make different strokes each cycle, the total travelled distance can characterize the application.

The speed of the piston rod determines both friction and wear of the seal systems. Therefore, it makes sense to divide the travelled distance into low speed travelled distance and high speed travelled distance. Especially the low speed travelled distance can be used as a condition monitoring indicator if historic data are available.

2.2.3. Stroke length distribution

For cylinders that make identical movements each cycle, information on stroke length distribution (number of strokes for a number of different stroke length ranges) should not contain new information. However, events like an emergency stop or the cylinder being moved in a manual mode, will show up in such a histogram.

In applications where strokes vary, it is a separate indicator for the actual load history. If the strokes are made around a certain equilibrium position, as found in (heave) compensating systems, it indicates what section of the length of the rod is mainly in contact with the linear bearings.

2.3. Position derived key figures

2.3.1. Maximum piston rod speed

Besides characteristics that relate to the position measurement directly, monitoring the speed of the piston(rod) is a simple, feasible, and useful function. There may be speed limits imposed on the product, e.g. based on the tribological systems (fluid, seals, bearings, scraper, rod surface, and shell surface) applied. Keeping track of the maximum speed can help to check if the application works as intended.

The speed is calculated from the position signal numerically. It is known that, depending on the algorithm used, this may result into inaccurate values when the signal-to-noise ratio of the position signal is suboptimal, especially for low speeds. Filtering techniques are often required to ensure a reliable figure for the maximum speed detected. Sufficient processing power must be available for this in the measurement system.

2.3.2. Maximum piston rod acceleration

Another key figure for the piston rod movement are the extreme values of its acceleration and deceleration. The application and the cylinder have been designed to function within certain limits of acceleration and deceleration. Monitoring the actual values may help to validate the intended use or carry out a root cause analysis in case of a malfunction.

The acceleration and deceleration value is calculated numerically using the speed as input. The inaccuracy issue as discussed in section 2.3.1 applies here as well.

2.4. Temperature based key figures

Of course, tracking of the absolute maximum and minimum temperature measured could help the user to assess to what extend the application has been within its temperature limits for use. Besides, a temperature zone residence time enables the assessment if these extreme temperatures are reached incidentally or reached for longer periods. Also the temperature zone residence time can be (part of) a condition monitoring indicator, as e.g. the lubrication and consequently wear of seal and bearings can be affected by the temperature (of the hydraulic fluid), either high or low.

3. Example

In **Figures 3 to 5**, an example is shown of the data read from a CIMSmart showing a practical implementation of the application monitoring key figures as described in section 2. It shows the categories defined for the movement history and stroke length distribution. It also reveals that with the maximum speed, acceleration and deceleration, time stamp information is available. As the CIMSmart can be switched off completely, this time stamp information is in terms of operating time. In this implementation, a reference date is retrieved from a PC, as soon as it is connected to the CIMSmart and a data reset command is given. Thus, the calendar date can be calculated. In this particular example, the CIMSmart has had downtime since the last reset of the acceleration and deceleration key figures, thus, the calendar date is estimated for those key figures.

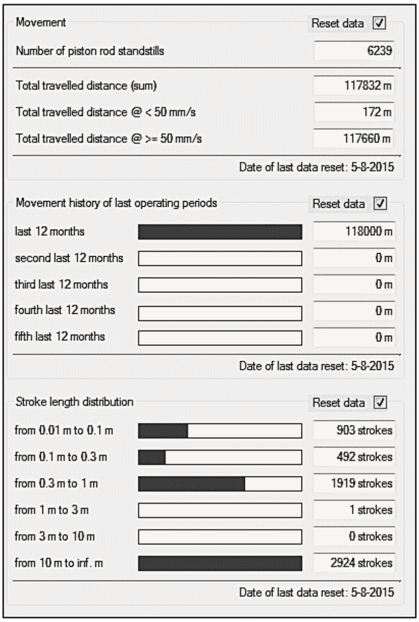

Figure 3: Example of key figures on position

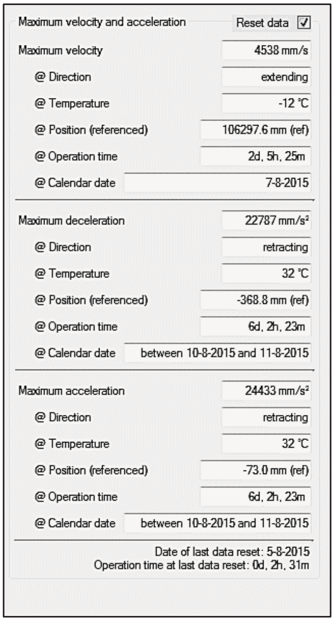

Figure 4: Example of key figures on speed and acceleration

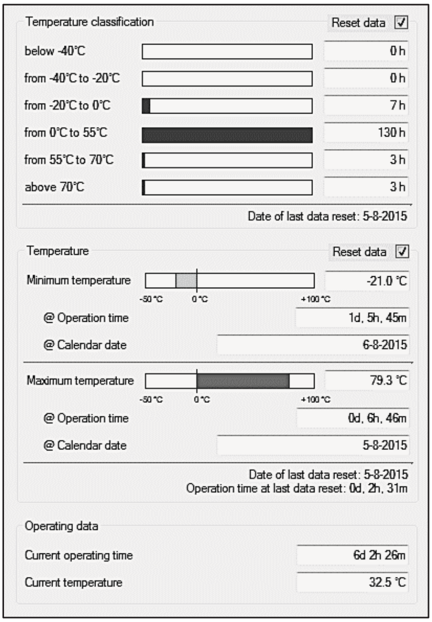

Figure 5: Example of key figures on temperature

4. Conclusions and future outlook

Various design concepts applied to the CIMS are focusing on reliability. Using an encoded rod pattern, covered by a robust coating, prevents loss of signal by wear or damage and still takes advantage of the optimal tribological properties of the coating. As there is no contact between the sensor and the rod, there are no additional moving parts or mechanical wear. Additionally, the differential Hall effect sensors compensate for air gap changes. With the added features on application monitoring, that partially can be used for condition monitoring as well, the sensor has made a significant step towards cylinder intelligence.

Developments by adding sensors (for e.g. hydraulic pressure, temperature, oil condition, but also accelerometers) will, when put at the right position inside the cylinder, further increase the possibilities to monitor both the application and the condition of the cylinder.

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