International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal | www.ijtsrd.com
ISSN No: 2456 - 6470 | Volume - 2 | Issue – 6 | Sep – Oct 2018

Condition Monitoring of Wear Progress in Hydrostatic Pumps

Emad Ali
Engineering Drives & Mechatronic Solutions
Bosch Rexroth AG in Bgm.-Dr.-Nebel-Str. 2, D-97816 Lohr – Germany

ABSTRACT
This paper represents a practical methodology for monitoring the wear in the displacement elements in hydrostatic pumps. The technique is based on appropriate signal processing of the output pressure wave which reflects the geometrical changes in the internal parts. The geometry deviates in case of wear and the degree of deviation can be spatially analyzed to gain an indicator to the wear progress. The method is effective and computationally efficient in comparison to other algorithms, for ex. wavelet transformation. The design is followed by a successful experimental validation, for a case of internal gear pump (IGP).

Keyword: *Condition Monitoring (CM), Hydrostatic Pumps, Wear Detection, Internal gear Pump (IGP)*

INTRODUCTION
Nowadays, the demand to improve the availability of the fluid power machines is increasing. The field of condition monitoring CM is challenged not just to signify a malfunction but furthermore to detect it in early phases. The hydrostatic pumps are considered the fundamental unit in any hydraulic systems, such as die casting and injection -moulding machines. Figure 1 depicts an overview of the schema that the paper focuses on. The working principle of the hydrostatic pumps, in general, is based on successive displacements of elements arranged in a rotational schema [1] and hence reveals a pulsating output flow rate [2]. See the measurement in Figure 2. The resulting pressure wave can be used to gain symptoms for faults such as sealing defects [6], [7].

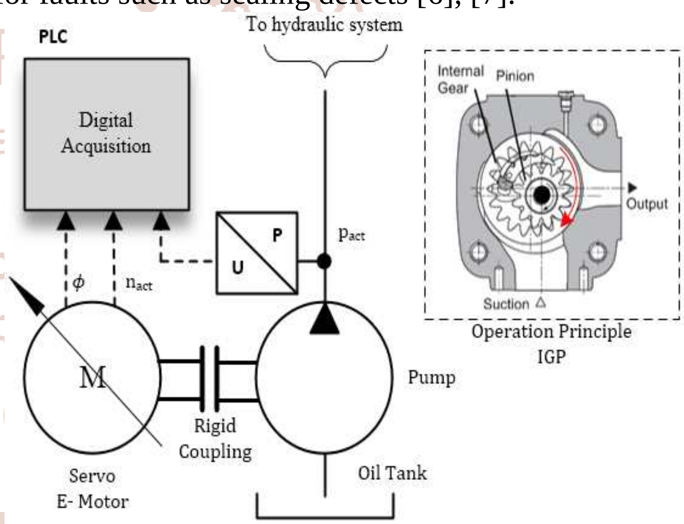

Figure 1: The schema of the pump operation

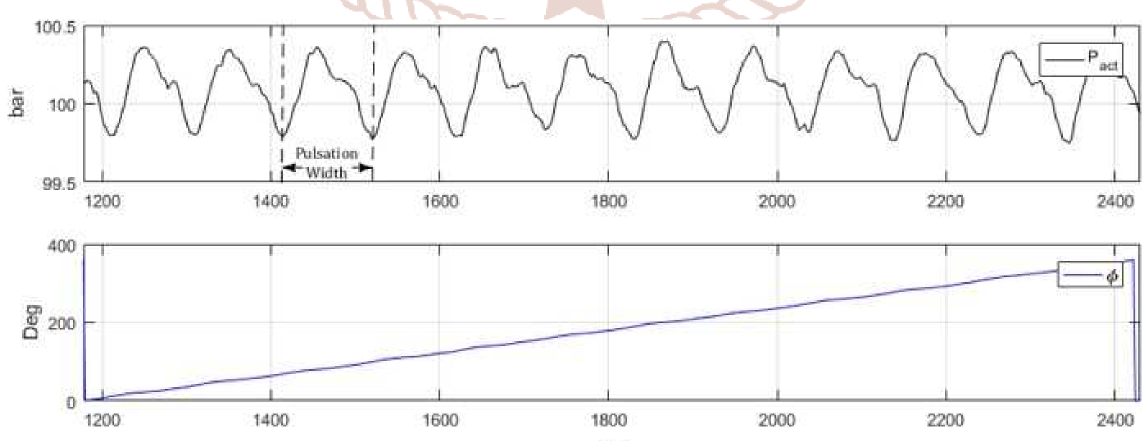

Figure 2: Sample 1 pinion revolution measurement of IGP (pressure pulsations, pinion angle)

The degradation of the components is often caused by erosion wear, whose progression is affected by the quality of the lubricating medium, i.e. the working oil.

The work in [4] simulated the fault of wear in one of the pistons in a case of axial piston pump. The problem thereby is the lake of the clear reference that de- scribes the wave in wear-free situation. The difficulty is encountered due to the dependency on the attached hydraulic capacity that is typically not pre-defined, the dependence on the oil properties and the manufacturing tolerances. The work in this paper profits from the acquisition of the rotational speed, and angle information that come up from the encoder unit in the servomotor, in combination with the pres- sure wave measurements.

Pressure Pulsations

The working principles of the hydrostatic pumps is similar so that the conclusions in [4] can be generalized. The form of the pressure pulsations depends on the geometrical properties of the pump, the compressibility of the fluid and the leakage flow rates, whereas the geometrical origin is the main cause [5]. The compressibility effect is remarkable if the oil has a portion of undissolved air [1]. For the case of the study, an internal gear pump , the frequency of the resultant pulsation f_p[Hz] is related to the rotational speed, n_{act} [rpm], and the number of the pinion teeth z_p,Eq. 1[5].

$$f_p = n_{act} z_p / 60 \qquad \textbf{Eq. 1}$$

The output flow rate Qcan be calculate dusing the speed, the total displaced volume per revolution $v_g$and the volumetric angular function$G(\phi)$

$$Q = n_{act} v_g G(\phi) \qquad \textbf{Eq. 2}$$

$$p_{act} = \frac{1}{h_c} \int Q \, dt \qquad \textbf{Eq. 3}$$

The function $G(\phi)$ differ from a pump type or model to another. Other system components such as hoses and cylinders have a damping effect on the resultant pulsation of the pressure wave, p_{act}[5] as these components increase the hydraulic capacity h_c.he exact pulsations amplitude of the output pressure wave p_{act} in turn, cannot be predicted as the rest of the system is not known in advance and the oil properties vary with changing environmental conditions. For these reasons, it is difficult for manufacturers to set such a value in the technical specifications of the pump.

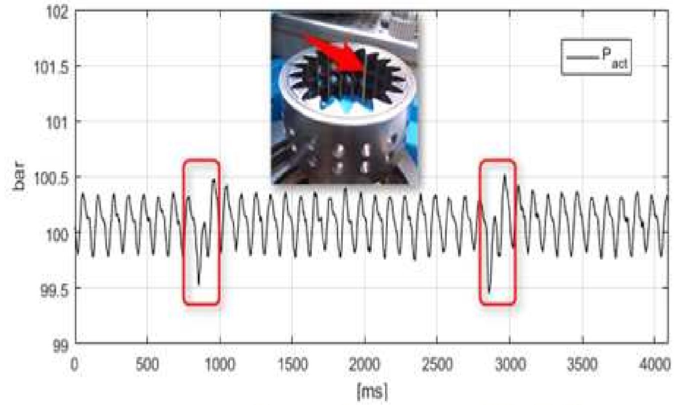

Figure 3: Test fault in internal gear with artificial wear in 1 tooth

The Partial-Wear Fault

The effects due to local wear (erosion), in one or more volumetric displacements, are regarded as disturbances on the homogeneity of the output pressure pulsations at steady state, **Error! Reference source not found.**. The wear spreading is assumed to be a slow process and normally has a discontinuous distribution within the pump. In the case of IGP, the progression of the wear, in order of magnitude of micrometers, can start up in the pinion, the internal gear or in the segments and the inner housing. The likely worn out component has softer material. Without loss of the generality, we regard the wear in the displacement elements, i.e. the chambers between gear teeth. The nature of wear progression would be detected as heterogeneity in the resulting pressure pulsation.

$$Measurement\ length\ [s] = \frac{60 \cdot N_{Mp}}{z_p n_{act}} \qquad \textbf{Eq.4}$$

$$N_{Mp} = smallest\ common\ multiple\ (z_p, z_i) \qquad \textbf{Eq.5}$$

$$\phi_w = 360 / z_p \qquad \textbf{Eq.6}$$

As could be interpreted from the measurement of one revolution at low speed in**Error! Reference source not found.**, the pulsations are not geometrically identical. Moreover, the combination of pinion and internal gear teethz_p , z_i respectively should be taken into consideration because the displacement chambers are based on their configurations. Due to this fact, the smallest common multiple of (z_p, z_i) should be the criteria of setting the min measurement length in order to regard all possible displacement chambers, Eq.4. The IGP under study has$z_p = 12$, $z_i = 18$, so the homogeneity should be monitored for 36 successive pulsations, i.e. 3 revolutions.

In order to monitor the wave, a straight Fourier analysis enables no localization and no capability to determine the width of a periodic heterogeneity that would quantify the wear progress. Other techniques such as wavelet transformation, that preserve the time information, are more convenient. However, the practical usability of the transformation encounters the following obstacles:

- The transformation is computationally complex for the application on PLCs
- Poor generalization; no common mother wavelet can be set for all pulsation forms. As the form may differ from a pumpto another (or type).
- The output wavelet coefficients in different scales are hard to interpret by machine human operators.

The Fingerprint Principle

As the pulsations form reflects the manufacturing tolerances, it should be constructed under this consideration. The form could be estimated for every pump unit directly as a "fingerprint". The idea behind this is to extract a reference pulsation, R P during wear-free situation in the first operation hours. Thereby, the RP can be estimated on the basis of vectors of points estimated as $f(\phi)$, where the pressure and angle signals are modulated to the geometrical width ϕ_w[deg], see **Error! Reference source not found.**.

$p_{act,i}(\phi)$is the instantaneous value of the pressure at the pulsation form i. This value can be derived by means of standard rectangular window, width $= \phi_w$ in the measurement vectorp_{act}

The RP could be the envelope of the ensemble (lower / upper) or directly elect the form whose integral is the highest.

The objective in this part is to avoid the forms that lay near to the extreme edges, as depicted in **Error! Reference source not found.**. The estimation of RP as the mean form of N_{MP} pulsations appears to be the best optical match.

$$RP(\phi) = \frac{\sum_{i=1}^{N_{MP}} p_{act,i}(\phi)}{\bar{p}N_{MP}}, \phi: \to \phi_w \qquad \textbf{Eq.7}$$

Mathematically, the formation is based on the extraction of the normalized mean of N_{MP} pulsations;Eq.7.

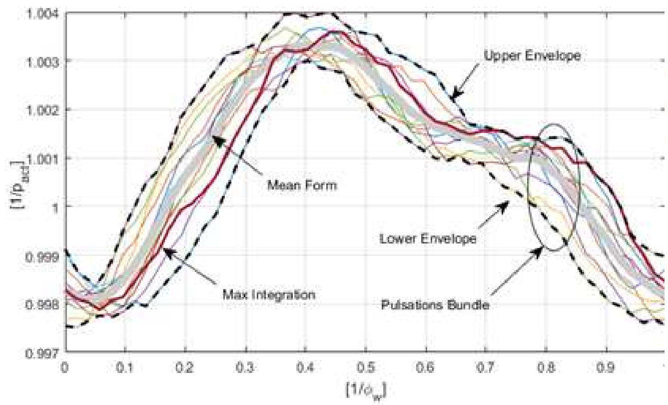

Figure 4: Pulsations bundle and 4 different alternatives to build the RP

$\bar{p}$ denotes the mean pressure value at steady state and is used in Eq.7 for normalization reasons.

Fault Detection

The heterogeneity as result of wear can be then measured as deviations in the similarity degree between any measured pulsation wave, MP, and the RP. The mathematical technique "cross correlation"[3], is suitable for this task, Eq.8.

$$\beta = \max\left(\sum_{\phi=-\infty}^{\infty} MP(\phi) \cdot RP(\phi+\tau), \tau: 0 \to \phi_w\right) \qquad \text{Eq.8}$$

The similarity to RP can be expressed by the unit less coefficientβ whose magnitude aids to relatively quantify the wear progress along the rotational angle. The total heterogeneity width indicates the spreading of the wear along the gear teeth (pinion / internal gear).**Error! Reference source not found.**.depicts the estimated β at the case of 1 tooth wear in the internal gear represented in **Error! Reference source not found.**.

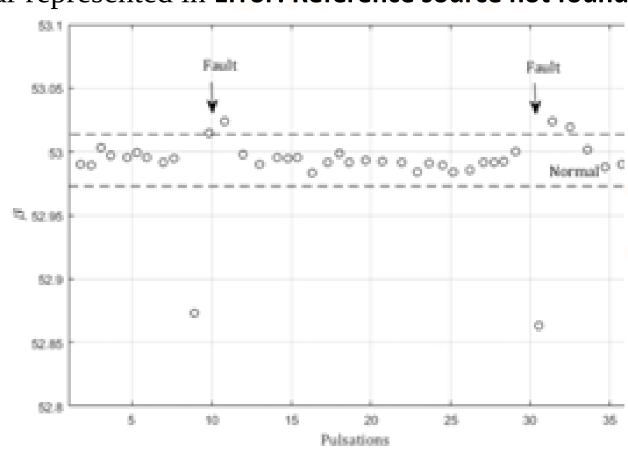

Figure 5: β Coefficient for pulsations at 100 [bar], 50 [rpm]

As seen, the values of the coefficient in normal variations are relatively near. The magnitude depends on the pressure, speed and the environmental conditions.

The normal, i.e. in wear free case, values range of value βcan be learnt in software modules at different set points (speed and pressure). So that the thresholds for monitoring the wear is automatically estimated.

Discussion

This approach has the following advantages:

- Robust against imperfect sampling.
- Applicable if both RP and MP have different number of samples at $\phi: 0 \rightarrow \phi_w$
- Robust against measurement delays between RP and MP
- Flexible as no fixed form is predefined
- Computationally simple in comparison to Wavelet transformation and therefore realizable on PLCs

The utilization of angle domain instead of time enables implicitly scaling the RP at different speeds, in a similar sense to wavelet transformation. However, the similarity coefficientsβ, must be estimated at each steady operation point (speed and pressure) as the system may damp the pulsations differently depending on the running frequency, f_p. Furthermore, the compressibility of the oil may vary with the pressure and in turn affects the amplitude of the pulsations.

It should be notified that in this experiment, the test rig has short pipe lines and the speed of the drive for this monitoring is relatively low. Disturbances that may result from Fluid waves reflection are not observed.

The frequency of the fault can help in isolating the origin of the wear (pinion\ internal gear) on the basis of rotational speed of each one. If the abnormality of β has temporal frequency f_p so the pinion gear is worn out, and at a frequency $= f_p z_p / z_i$, the internal gear is the worn component. An offset in the mean value indicates leakage in the sealing This causes general damping in the pulsation amplitude.

The width of the deviation in β indicates the spread of wear to other teeth elements, this information can be derived by integrating the angular distance throughout the deviation $\Delta\beta$.

$$Wear\ Level = \sum_{i=1}^{N_{MP}} \Delta\beta_i(p,n)\phi_w \qquad \text{Eq. 9}$$

The analysis of the wear level temporal progress and their dependency on the oil quality for various pump type is left for future research works.

REFERENCES

1. Bauer, G. 2005. *Ölhydraulik*. Vieweg+TeubnerVerlag, Wiesbaden.
2. Ivantysyn, J. and Ivantysynova, M. 2003. *Hydrostatic pumps and motors*. *Principles, design, performance, modelling, analysis, control and testing / Jaroslav Ivantysyn and Monika Ivantysynova*. Tech Books International, New Delhi.
3. Kido, K. 2015. *Digital Fourier Analysis*. *Fundamentals*. Undergraduate Lecture Notes in Physics. Springer New York, New York, NY.
4. Li Z. 2005. *Condition Monitoring of Axial Piston Pump*. Master, University of Saskatchewan.
5. Matthies, H. J. and Renius, K. T. 2008. *Einführung in die Ölhydraulik*. Vieweg + Teubner, Wiesbaden.
6. May, M., Sepehri, N., and Kinsner, W. 2014. Hydraulic Actuator Internal Leakage Detection Using Cross-Correlation Time Series Analysis. In *ASME/BATH 2014 Symposium on Fluid Power and Motion Control*. ASME, V001T01A003.
7. Xuanju S. 2015. *Development of a hydraulic component leakage detecting system using pressure decay signal*. Master, University of Northern Iowa.