ISSN 1454 - 8003
Proceedings of 2022 International Conference on Hydraulics and Pneumatics - HERVEX
November 9-10, Băile Govora, Romania

ANALYSIS OF DYNAMIC REGIME OF A HEAVY MACHINE FOR SUPPLEMENTARY POWER CONSUMPTION EVALUATION

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Abstract: *In this paper the author proposed some indicators for performance evaluation in dynamic steady of working time in the case of heavy machines. Thus, it was monitored the hydraulic parameters of a wheel loader knowing it's as a machine with an intense and varied working regime characterized by over-pressurization occurred because of excessive loads that appear when execution different tasks during technological cycle on construction site. Based on hydraulic parameters, it were evaluated engine power required for loading phase and, taking into account by the performance indicators, the supplementary power needed for task execution.*

Keywords: *Loader, hydraulic system, power, performance, indicators*

1. Introduction

In the last years, a large number of performance indicators has been introduced to measure the quality of products from different fields of industry. In particular, in this paper, about quality evaluation of construction machines are addressed. A method has been proposed to use an algorithm for operational performance evaluation of wheel loader. In the first step, we need to identify which parameter is being analyzed to define level of machine performance. Literature references indicate the state of knowledge about this aspect and some case studies are developed around the analysis of following parameters: energy consumption, power needed, pressure into the hydraulic circuit, engine torque or resistant forces developed at working tool etc. The novelty of the study presented in this paper consists in developing the set of indicators in order to measure the performance as dynamically state condition from a wheel loader.

2. Power monitoring

The engine power of a wheel loader is generally diverted to the transmission system, the hydraulic system, and accessories. The hydraulic power and the drivetrain power are the two largest power consumers in the wheel loader, because both systems act together when the machine work into the pile. According to engineering experience [1], we have reduced the auxiliary power being around 10% from total engine power. The way the power is distributed between hydraulics and drivetrain depends on how much power is requested from the different systems. Working phases involve the complex interaction of the loader power train, hydraulics, implement linkage, and steering system. Machine behavior is a function of these systems and their interactions and how the operator uses them. It is difficult to determine how a change in an individual system can affect the overall machine performance [2]. These interactions are highly nonlinear and dynamic, making them difficult to understand completely. The hydraulic drives have many factors that affect the power losses and for performance improvement the modern wheel loaders use load sense hydraulics instead of the open-center hydraulic system. In addition, for hydraulic-driven machines (loaders lifting trucks etc.), operating in a cyclic manner the energy consumption can be considerably reduced, by using accumulators as energy storage devices. Thus, it possible to balance forces in lifting system and to be used for regenerative braking of loads. Combined with a secondary controlled unit, the energy transformation can be performed with low losses [3]. However, high-amplitude oscillations are found in the acquired pressure signals due to the dynamic behavior of the machine, especially during the phase of loading the bucket or moving towards unloading in the truck [4,5]. A more detailed knowledge of these aspects is opportune and creates the prerequisites for the introduction of a new criterion for evaluating the performance of a construction machine [5, 6]. The identification of all phases of the working cycle of loader is needed to know the particularities of each of them, as variation of the load intensity. With the information of all the phases in the cycle, an adequate energy management can be optimized not only for one phase, but even over one cycle [7]. Thus, the following phases can be distinguished [8]: bucket filling, leaving bank, retardation, reversing, towards lead receiver, bucket emptying, leaving load receiver, retardation and reversing, towards bank and retardation at bank. However, in order to minimize the execution time of the loading and transport works, the short work cycle with the loader (in V-type) is recommended (it contains fewer working phases). Next, the case study it was developed on the LDH loader (45 CP) with hydraulic scheme given in the Figure 1. Details about experimental tests, setup used, acquisition and processing aspects were the subject of a previously published paper [9-11]. By using a high pass filtering of the load pressure and flow measured signals (Fig. 2), the effective power can be evaluated as global parameter that are included both excitation sources generated by the internal (depending on the type of hydraulic circuit and apparatus used, commands for execution tasks, the control of functional parameters etc.) and external perturbations (as response to the resistant forces developed when the bucket penetrates the pile), all induced into driven system of loader.

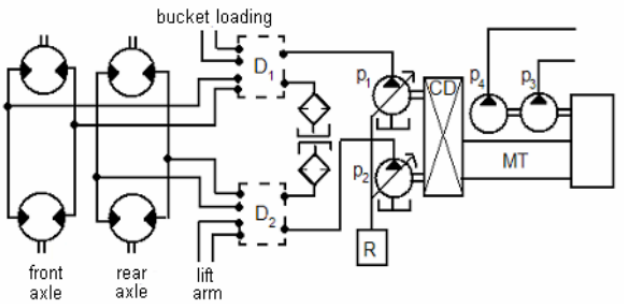


Fig. 1. Hydraulic wheel loader system circuit (MMT 45, Romania)

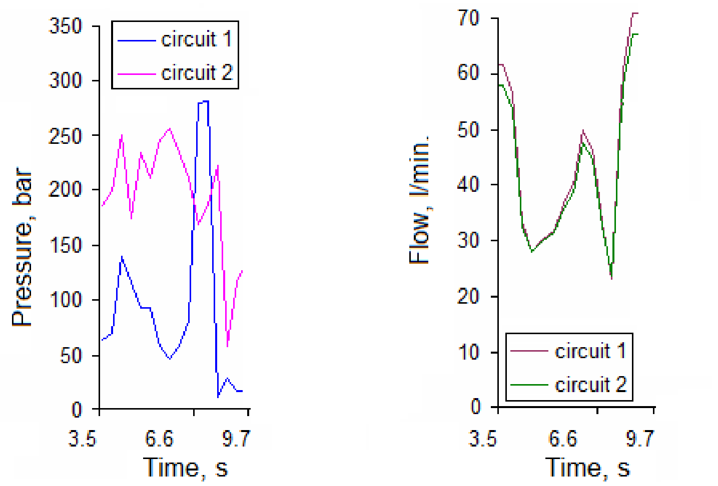


Fig. 2. Pressures and flows monitoring over the typical working cycle of loader (material: non-cohesive soil)

The hydraulic system power shows the various change in working cycle of loader and can be calculated as

$$P = \frac{\Delta p \cdot Q}{60 \cdot \eta} \tag{1}$$

where Δp is the differential pressure between the inlet and outlet pressures, Q is the volume flow rate, and η is the overall efficiency. After evaluating the total power (as the sum of the powers of both circuits), its average value is determined for each phase of the work cycle. The results obtained in two cases of working (pile constituted from non-cohesive soil and, respectively, cohesive soil), only for loading bucket phase (noted as Phase 2) are shown in the Figure 3.

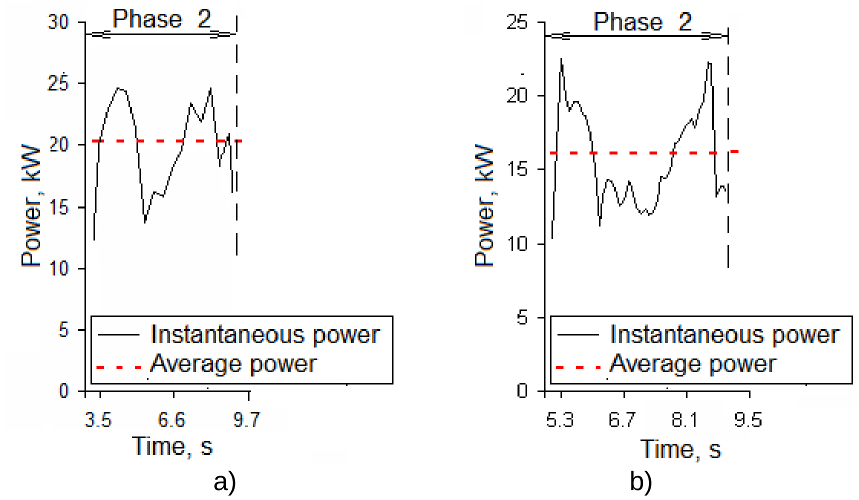
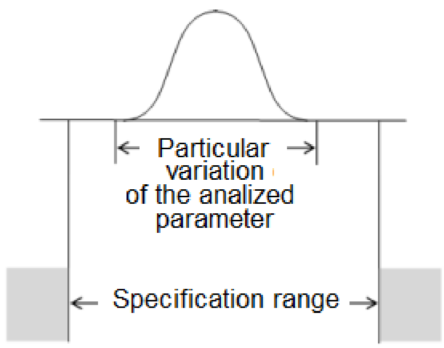


Fig. 3. Selecting and processing of the power signal from loading bucket phase, in two working cases: a) non-cohesive soil (wet sand); b) cohesive soil.

As consequence of the interactions between hydrostatic system, working equipment action, type of the displacement mechanism (on wheels) and irregular road on the construction site (in poor condition frequently) the power consumption have variations [12]. Based on these signals (represented in fig. 3), the working performance of the loader will be identified, for two different working environments, in order to supplementary power consumption evaluation (P).

3. Statistical signals processing

The statistical processing of the experimental data includes histograms, probability diagrams, and general statistics of data. Together, they provide means for analysis of the monitored data, especially for checking whether the data is normally distributed, because the control charts theory assumes normal probability distribution (Fig. 4). Control limits of the measured data can be calculated from sample points, but for improvement of processing quality, it is recommended to analyze the distribution of the average value compared to the individual values of the samples (Fig. 5).



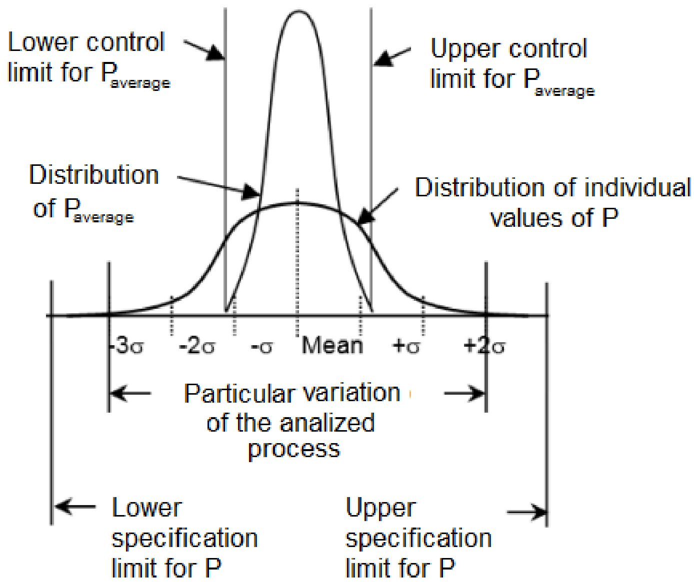


Fig. 4. Normal distribution of the samples points **Fig. 5**. Comparative distribution limits of the sample points

These aspects will be taken into account when developing the data processing quality control algorithm, in the future work. At this stage, only the verification of the applicability of the proposed method will be demonstrated. For a basic evaluation, general statistics of the monitored parameters (pressure and flow) were carried out with the following operators: random variable (P_i), mean value ($\bar{P}$), root-mean-square (*RMS*), standard deviation (σ) and variance (σ^2). Based on these statistical operators, the following hypotheses can be stated necessary to formulate additional performance criteria in intense dynamic regime of a fast-speed loader, thus:

- random variable of power (P_i) differs from a working cycle to another. This operator quantifies stationary values of each phase;
- average value of power ($\bar{P}$) leads to the highlighting of instantaneous dynamic stresses at the change from one phase to another. By evaluating of this statistical operator, the real power of the machine is quantified;
- root-mean-square of power *(RMS)* is used to quantify the overall energy content of the signal;
- standard deviation of power (σ), on the individual working phase, puts into evidence the transitory behaviour of each of them, and it quantifies the static power of the machine;
- variance of power (σ^2) it measures the degree of dispersion of the instantaneous power data around the power sample's mean. It is used to compare the relative performance of each working phase with imposed performance to achieve the best power consumption allocation.

4. Indicators for dynamic global performance

Based on a set of four indicators defined in the Table 1, the global (dynamic) performance of the charger is evaluated.

Table 1: Defining of indicators

Indicator name	Formula
Indicator for static power evaluation	$i_1 = \frac{P_s}{P_{max}}$
Indicator for dynamic power evaluation	$i_2 = \frac{P_d}{P_{max}}$
Indicator for real (effective) power evaluation	$i_3 = \frac{P_r}{P_{max}}$
Indicator for intensity of the dynamic power state	$i_4 = \frac{P_r}{P_s}$

It was introduced the next denotes with the following significations: P_s - power in steady regime and it is estimated by the statistical average of the instantaneous values purchased during the respective phase; P_d - additional power necessary for the transitory regime of the machine; P_r - the real needed power in to real loader conditions; P_{max} - maxim engine power.
The results of processing power data are centralized in the Table 2, for bucket loading phase and for two different material categories.

Table 2: Processing power data

Phase	Material	Operators	Power, kW
Loading bucket	Non-cohesive soil (wet sand)	RMS	36,631
		Standard deviation	9,041
		Mean	35,498
		Variance	81,746
	Cohesive soil	RMS	32,358
		Standard deviation	5,691
		Mean	31,853
		Variance	32,393

For example, Figures 6 and 7 show the four indicators (i_i, i = 1…4) for identifying the dynamic performance of a loader, in the bucket loading phase.

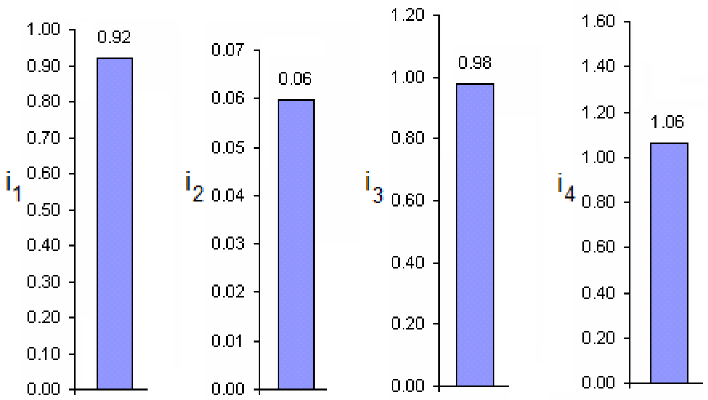


Fig. 6. Indicators values for global performance of dynamic working regime in the loading bucket phase (material: non-cohesive soil, wet sand)

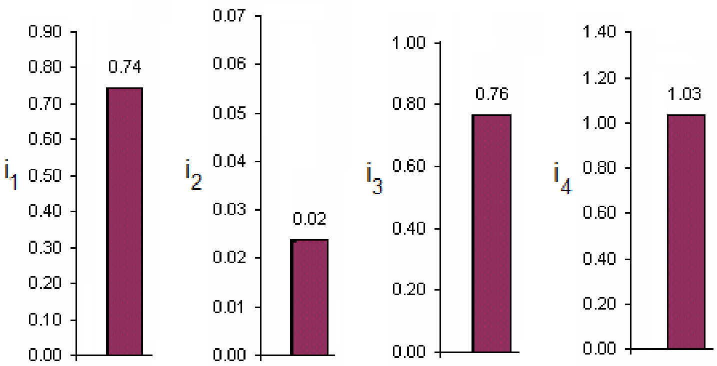


Fig. 7. Indicators values for global performance of dynamic working regime in the loading bucket phase (material: cohesive soil)

In demanding working conditions, comparing the performances of two different types of construction machines can be done by evaluating the i_4 indicator. Thus, in this case study, the difference caused by the type of material loaded in the bucket is noted, which is found in a percentage of 6% compared to 3% in the dynamic behavior of the loader's driven system and, implicitly, in the supplementary engine power consumption. Therefore, variance values indicate a significant difference of intensity of the bucket loading phase: 81,746 (non-cohesive soil) in respect with 32,393 (cohesive soil).

5. Conclusions

The topic of this work is part of the current trend of global identification of the performance of a machine, in general mode (by monitoring one or more reference parameters) and by specialization by types of machines (by elaborating valid reference standards for construction machines that have an intense and varied dynamic working regime).
In the study presented in the paper, the following conclusions were highlighted:
- static indicator (i_1) shows the percentage of the machine's power required for operation in stable working mode;
- dynamic indicator (i_2) quantifies the additional power required in transient regimes or with intense dynamics. Knowing the values of this indicator is of major importance in evaluating the additional power, being closely related to the size of the dynamic loads from the working phases of the technological process with fast chargers;
- real indicator (i_3) provides qualitative and quantitative information about the power reserve and its efficient use by the machine;

- indicator (i_4) characterizes the intensity of the dynamic state and, implicit, of the supplementary consumption of engine power as response of overloads into mechanic and hydraulic systems (sometimes also due to the operator's lack of experience).

Thus, the set of indicators described above can constitute a new reference criterion in the evaluation of the additional power consumed in the work phases of the construction machinery characterized by regimes with intense dynamics, with a view to an individual but also global characterization of the work performance.

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