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ANALYSIS OF THE DYNAMIC BEHAVIOR OF THE HYDRAULIC VIBRATION SYSTEM OF THE COMPACTOR EQUIPMENT, UNDER DIFFERENT OPERATING CONDITIONS

Daniel Sorin MIRON[1], Carmen Nicoleta DEBELEAC[1]

[1] "Dunarea de Jos" University of Galati, Engineering and Agronomy Faculty in Braila, Research Center for Mechanics of Machines and Technological Equipments, Braila, Romania

Abstract: *This paper addresses the design and operation of the hydraulic vibration generating system of a compactor, focusing on some operational aspects with significant impact. A major problem is the inability of the system to adequately regulate the hydraulic flow, especially during sudden changes in the working regime, which leads to sudden pressure fluctuations and hydraulic shocks. These shocks negatively influence the stability, efficiency and lifetime of the hydraulic actuation system of the roller drum. The paper presents the solutions adopted by the manufacturers for operational performance improvement of these systems.*

Keywords: *Dynamic behavior, hydraulic vibration system, compactor equipment, working regime, analysis*

1. Introduction

The analysis of the dynamic behavior of the hydraulic vibration system in compactor equipment under various operating conditions is critical for understanding the system's performance, reliability, and efficiency. Hydraulic vibration systems in compactors are responsible for generating the vibrations necessary for soil and material compaction, which makes their stability and dynamic response essential in achieving the desired compaction results while ensuring the longevity of the equipment. The hydraulic vibration system of a compactor consists of a hydraulic pump, control valves, hydraulic motors or cylinders, and vibratory drums. All these components work together to generate and control the mechanical vibrations transmitted to the compactor drum. The roller's ability to efficiently transfer these vibrations to the terrain depends largely on the system's dynamic behavior, including how it responds to changes in pressure, flow, load, and external forces.

2. Operational aspects of vibratory rollers

Operating conditions that affecting the hydraulic system dynamics of the compactor equipment are:

a) Load fluctuations, particularly during transitions between compacting different types of soil or material, cause sudden changes in hydraulic pressure and flow. These variations can result in unstable operation, pressure surges, and hydraulic shocks, leading to potential damage to the system components.
b) Pressure and flow control are very important because the effective regulation of hydraulic flow and pressure is necessary to maintain constantly vibration frequencies and amplitudes, which are determinant for an adequate compaction. A challenge is preventing hydraulic shocks during sudden pressure changes, which can occur due to load shifts or rapid changes in the operating regime.
c) The viscoelastic properties of the soil significantly impact the dynamic response of the compactor's hydraulic vibration system. Softer, more elastic soils absorb more vibration energy, requiring adjustments in system settings to maintain the compaction process efficiency. Conversely, denser, more compact soils may cause increased hydraulic pressure, further influencing the hydraulic system's behavior.
d) The frequency and amplitude of the hydraulic vibration system need to be carefully controlled to match the operational requirements. Higher frequencies may be necessary for compacting finer materials, while lower frequencies are more effective for coarser soils. Studies show that improper

control of these parameters can result in inefficient compaction and increased wear on the hydraulic components.

e) Hydraulic fluid properties, as viscosity, density, and temperature sensitivity of hydraulic fluids directly influence the system's dynamic behavior. Thus, the high-viscosity fluids can cause increased resistance in the hydraulic system, reducing flow and efficiency, while lower-viscosity fluids may not provide adequate damping, leading to excessive vibrations and shocks.

The impact of these operational factors on the dynamics of hydraulic actuation systems in vibratory compactors has been a subject of global research. The most significant results are outlined below.

3. Simulation of dynamic behavior of hydraulic system

To better understand the dynamic behavior of the hydraulic vibration system, dedicated simulation environments such as AMESim, Matlab or other dynamic modeling tools are often used. The results of these simulations allow engineers to predict how the system will behave under various operating conditions, including changes in load, pressure, and fluid properties. For example, Wang Haifei (2003) studied the mechanisms of hydraulic impact and recommends measures to prevent hydraulic shocks, highlighting the importance of control systems in improving system resistance under different working conditions [1]. Ma and Yang (2016) use the AMESim environment to model the roller hydraulic vibration system and understand how changes in the system parameters influence the overall performance and reliability of the construction machine [2]. Figure 1 shows some examples of developed schemes for simulating the behavior of the hydraulic system that drives the movement of the compactor or the vibration generator of the drum [1-3].

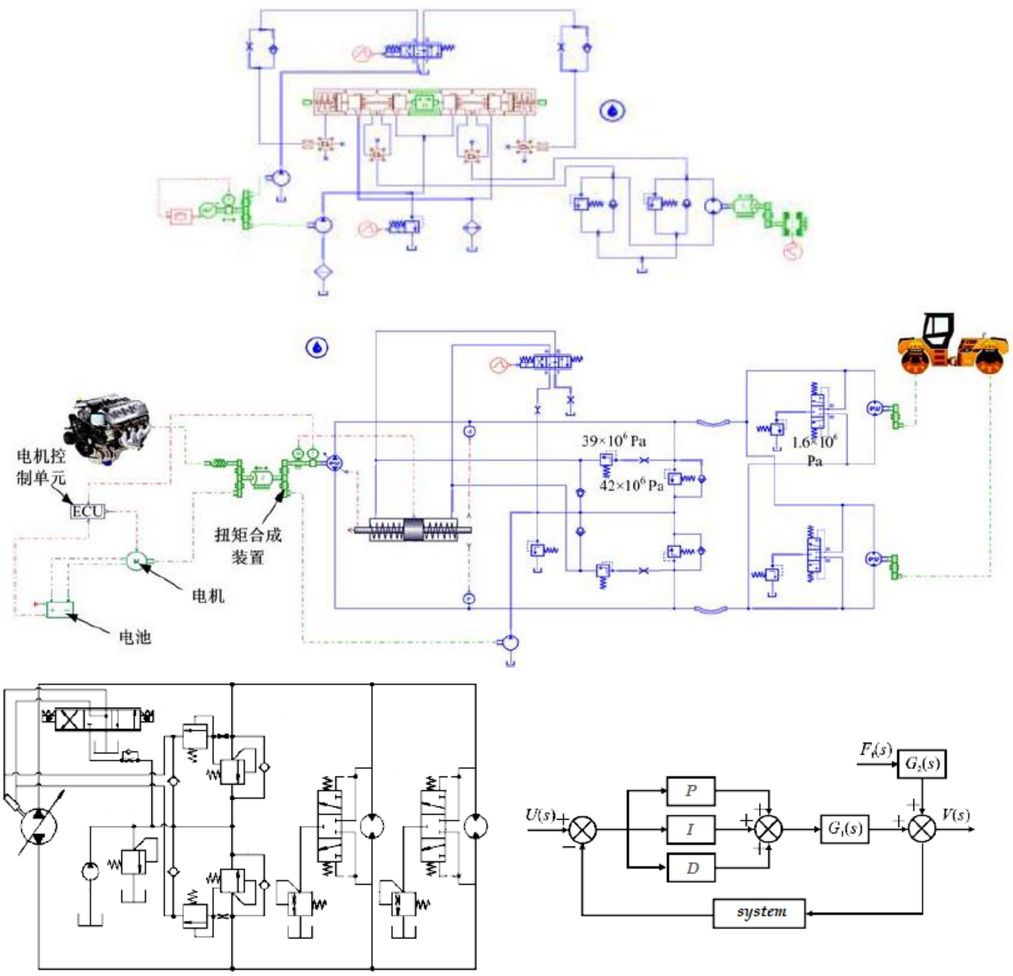

Fig. 1. Scheme for AMESim and Matlab environment simulation

Studies such as those by Debeleac et al. (2019) emphasize the nonlinear dynamic behavior of the system when compacting different construction materials [4]. Simulation tools like Matlab are often used to model and predict how the system responds under different loading conditions.

The dynamic response of the vibrating compactor roller is influenced by several factors, including the viscoelastic properties of the soil being compacted. Studies have shown that these material properties significantly affect the system's stability and its ability to absorb and dampen the vibrations generated during operation [5]. To alleviate these issues, this paper proposes incorporating control elements into the hydraulic actuation scheme to improve flow regulation. Additionally, the authors employ Matlab simulation software to model the dynamic behavior of the hydraulic system under varying conditions such as different loads, pressure variations, and the use of various hydraulic fluids.

This approach is in line with other studies that have modeled the rheological interaction between the working tool and the ground during vibratory compaction. Such modeling helps in understanding the material deformation and energy dissipation processes that occur during compaction, which are critical for optimizing the hydraulic system's design [6].

The results obtained from these simulations show that large load fluctuations can cause rapid changes in hydraulic flow, resulting in pressure spikes that produce hydraulic shocks. These sudden pressure increases can lead to significant system damage, including premature wear of components and potential system failure. Similar findings have been reported by other researchers, particularly in the computational assessment of vibratory compaction processes for different terrains. These studies emphasize that improper regulation of hydraulic flow can result in system breakdowns and reduced performance, especially in harsh construction environments [7].

An additional phenomenon observed in hydraulic systems is "pressure resonance," which occurs when the system's natural frequency aligns with the excitation frequency from the hydraulic motor. This resonance can lead to severe pressure spikes and damage the hydraulic system. Such phenomena further underscore the importance of effective control mechanisms and damping solutions to prevent resonance and other harmful effects in vibratory systems [8].

In order to prevent hydraulic shocks and enhance system reliability, various control strategies are explored in this paper, including the use of accumulators, pressure-relief valves, and advanced control algorithms. Similar methods have been proposed in the literature, where accumulators act as buffers to absorb excess pressure surges, mitigating the impact of sudden pressure changes [2, 9]. Similar results have been observed in studies focusing on hydraulic systems in construction machinery, where sudden flow or load changes can induce system shocks, increasing maintenance demands and operational inefficiencies [10,11]. The paper offers solutions aimed at preventing these shocks, particularly during start-up, by reinforcing the hydraulic system, which is especially crucial for heavy rollers used in construction.

For example, the inclusion of accumulator systems or pressure-relief valves has been proposed to absorb excess pressure surges, reducing the risk of system failure [12]. Ultimately, the proposed measures are aimed at improving the performance of hydraulic systems, minimizing maintenance costs, and increasing the reliability of construction equipment in demanding environments. The approach aligns with other research highlighting the importance of shock prevention and flow regulation in hydraulic systems used in industrial applications [13].

The selection of hydraulic fluids also plays a significant role in system performance. Fluid viscosity and temperature dependence have a direct impact on hydraulic flow and pressure regulation. Research has demonstrated that optimizing fluid properties for specific operating conditions can reduce the risk of hydraulic shocks and improve the overall efficiency of the system [8, 14]. For instance, the density and viscosity of the working fluid significantly influence the system’s ability to maintain stable operation under varying loads and temperatures. Addressing these factors can enhance the compactor's performance and extend its operational life [15].

In order to improve the aspects produced by the factors presented previously, the manufacturers of compactors have implemented various solutions to improve the dynamic stability of the hydraulic vibration system, presented in detail in Table 1.

Table 1: The main control strategies for dynamic stability of the hydraulic system

Control strategies	Description
Feedback Control Systems	To uses the real-time feedback from sensors to adjust hydraulic pressure and flow in response to changes in load and terrain conditions
Pressure-Relief Valves	To mitigate the effects of sudden pressure surges, pressure-relief valves can be installed to release excess pressure and prevent hydraulic shocks
Accumulators	These devices absorb pressure fluctuations and act as buffers to smooth out rapid changes in hydraulic flow, reducing the likelihood of system damage
Variable Displacement Pumps	Adjusting the flow rate in response to operational requirements it can help maintain consistent vibration characteristics, regardless of external conditions

Simulation-based analyses help identify potential instabilities, failures, and inefficiencies that could occur under real construction machine operating conditions. By virtually testing different case scenarios and control strategies, engineers come up with solutions to optimize hydraulic system design, control mechanisms and functional parameters to improve the reliability and performance of compactors. This approach brings great benefits especially when analysing the complex interactions between the hydraulic components of the actuation circuit, the vibration system and the external environment.

4. Conclusions

The dynamic behavior of the hydraulic vibration system in compactor equipment is influenced by a variety of operating conditions, including load changes, soil properties, fluid characteristics, and system configuration. Understanding and controlling these factors is essential for optimizing system performance, preventing hydraulic shocks, and ensuring the longevity of the equipment. Through advanced simulation tools and effective control strategies, engineers can design more robust hydraulic systems capable of performing reliably under a wide range of working conditions.

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