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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

The journal is published 4 times a year and contains publications in the following main areas:

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Methods for improving the efficiency of maintenance service for the hydraulic system of the "XCMG XE230C" excavator

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Abstract: The operational efficiency of modern hydraulic excavators used in construction and earthmoving operations largely depends on the technical condition of their hydraulic systems. The XCMG XE230C excavator, as a medium-class heavy construction machine, is widely employed under intensive working conditions, which impose significant mechanical and hydraulic loads on its components. This study examines methods for improving the maintenance efficiency of the hydraulic system of the XCMG XE230C excavator based on international scientific literature, operational engineering practices, and modern diagnostic maintenance approaches. During the research, the effects of hydraulic fluid contamination, filter resistance, internal leakage, pressure losses, and failure intensity on machine productivity were evaluated. Traditional scheduled maintenance was compared with condition-based maintenance strategies. The findings indicate that a diagnostic monitoring-based maintenance approach can significantly extend component service life, reduce the frequency of failures, minimize unplanned downtime, and improve the overall operational reliability of the excavator. The proposed maintenance optimization model demonstrates practical applicability for construction equipment operating under variable loading and harsh environmental conditions.

Keywords: XCMG XE230C, excavator, hydraulic system, maintenance service, diagnostics, reliability, hydraulic pump, filter contamination, hydraulic fluid, pressure loss, condition monitoring, MTBF, failure intensity, operational efficiency, preventive maintenance

1. Introduction

Today, hydraulic excavators are among the most essential technological machines used in construction, road engineering, mining, and earthmoving industries. Their operational productivity, energy efficiency, and technical reliability depend significantly on the condition of the hydraulic system. In hydraulic excavators, the hydraulic system acts as the "power heart" of the machine, converting the mechanical energy generated by the engine into useful motion for actuating the boom, arm, bucket, slewing mechanism, and travel system. Therefore, any malfunction within this system directly affects the performance of the entire machine.

The XCMG XE230C excavator is a medium-class hydraulic excavator with an operating weight of 23,520 kg, equipped with a 169 hp ISUZU CC-6BG1TRP diesel engine. This machine is widely used in intensive excavation and construction operations where working conditions often involve heavy dynamic loads, dusty environments, fluctuating ambient temperatures, and prolonged continuous duty cycles. Such operational conditions accelerate hydraulic fluid degradation, filter contamination, volumetric losses in pumps, and internal leakage in hydraulic cylinders.

International engineering experience indicates that a substantial proportion of hydraulic system failures result not from manufacturing defects but from inadequate maintenance practices. Conventional scheduled maintenance models rely on fixed time or operating-hour intervals prescribed by manufacturers. However, in real working environments, machine loading conditions vary significantly depending on soil characteristics, operator behavior, ambient conditions, and operational intensity. Consequently, some components are replaced prematurely while others continue operating beyond safe wear limits.

Modern maintenance engineering increasingly emphasizes condition-based maintenance (CBM) and predictive maintenance (PdM) strategies. These approaches enable real-time assessment of equipment condition using measurable technical parameters rather than relying solely on predefined schedules. This allows maintenance interventions to be optimized according to actual machine health.

The primary objective of this study is to develop scientifically grounded methods for improving maintenance efficiency in the hydraulic system of the XCMG XE230C excavator and to evaluate their impact on reliability, energy performance, and operational cost effectiveness.

Literature Review

The reliability and maintenance of hydraulic machinery have been extensively investigated in international engineering research. According to Parker Hannifin (2021), more than 70% of hydraulic component failures are directly associated with contamination of hydraulic fluid. This finding highlights the critical importance of fluid cleanliness management and filtration quality in hydraulic maintenance programs.

Technical engineering documentation published by Bosch Rexroth (2020) indicates that internal leakage and pressure pulsation in hydraulic systems may reduce overall energy efficiency by 10–20%, particularly in high-pressure mobile hydraulic equipment such as excavators. Excessive leakage not only reduces hydraulic performance but also increases fuel consumption and accelerates component wear.

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Totten (2019), in his research on hydraulic fluid technology, emphasizes that oxidation, thermal degradation, and viscosity variation significantly affect hydraulic pump and valve longevity. These degradation mechanisms become particularly severe in machines operating under continuous heavy-duty cycles.

Jardine, Lin, and Banjevic, in their work on maintenance engineering, classify maintenance strategies into preventive, corrective, and condition-based maintenance approaches. Their analysis demonstrates that condition-based maintenance can reduce overall maintenance expenditure by 25–40% compared with conventional scheduled servicing.

Mobley (2020) identifies vibration monitoring, thermal diagnostics, and pressure trend analysis as effective tools for early fault detection in industrial machinery. These methods are especially valuable in identifying developing failures before catastrophic breakdown occurs.

The ISO 4406 standard serves as an internationally recognized benchmark for hydraulic fluid contamination classification. Industrial studies show that maintaining fluid cleanliness within recommended ISO classes can substantially extend hydraulic component lifespan.

Manufacturer technical documentation for the XCMG XE230C provides standard maintenance intervals; however, these schedules do not adequately account for variable real-world operational conditions.

The reviewed literature clearly indicates that integrating real-time operational monitoring with conventional maintenance procedures represents a scientifically and practically justified approach for improving hydraulic excavator reliability and maintenance efficiency.

2. Research methodology

Problem Statement

Modern hydraulic excavators are complex engineering machines equipped with multi-circuit high-pressure hydraulic systems, where operational reliability is strongly dependent on maintenance quality. The XCMG XE230C excavator is one such machine operating under intensive service conditions, where hydraulic components are continuously subjected to mechanical stress, thermal loading, pressure fluctuations, and hydrodynamic forces. Practical engineering observations indicate that failures within the hydraulic system are among the leading causes of unplanned machine downtime.

The core engineering problem lies in the fact that conventional maintenance practices are generally based on fixed service intervals recommended by the manufacturer, typically measured in operating hours. However, actual operating conditions vary considerably depending on excavation intensity, environmental temperature, dust concentration, soil hardness, operator behavior, and duty cycle fluctuations. Consequently, maintenance schedules based solely on fixed intervals do not accurately reflect the real wear state of hydraulic components.

For example, replacing hydraulic filters according to scheduled intervals without considering actual contamination levels may result in either premature replacement or delayed maintenance. Similarly, hydraulic oil replacement based only on operating hours does not account for actual physicochemical degradation caused by thermal stress, oxidation, or contamination. Such limitations lead either to unnecessary maintenance expenses or to severe failures caused by overdue servicing.

In the XCMG XE230C excavator, hydraulic pumps, directional control valves, cylinders, and pipeline systems all contribute to energy losses through pressure drops, internal leakage, and volumetric inefficiencies. As components wear over time, the hydraulic system efficiency decreases, resulting in reduced productivity, increased fuel consumption, and elevated operational costs.

Therefore, the scientific problem addressed in this study can be formulated as follows**:** to develop an efficient, reliable, and economically optimized maintenance model for the hydraulic system of the XCMG XE230C excavator that reflects real operational conditions rather than relying exclusively on fixed maintenance intervals.

Materials and Methods

The XCMG XE230C hydraulic excavator was selected as the primary research object due to its widespread industrial application, relatively high hydraulic complexity, and intensive operating conditions commonly observed in construction and earthmoving sectors.

Table 1

Main Technical Specifications of the XCMG XE230C Excavator

Parameter	Value
Operating weight	23,520 kg
Engine model	ISUZU CC-6BG1TRP
Engine power	169 hp
Maximum torque	637 Nm
Bucket capacity	1.1 m³
Maximum travel speed	5.5 km/h
Fuel tank capacity	400 L
Engine displacement	6490 cm³
Hydraulic system type	Multi-circuit high-pressure system

The methodological framework of this study combines hydraulic engineering analysis, reliability theory, technical diagnostics, and maintenance optimization principles. The analysis focused on the most significant operational indicators affecting hydraulic system performance, including hydraulic pressure, flow rate, power losses, filter contamination, hydraulic fluid condition, failure intensity, and component reliability.

Hydraulic power was determined using the standard fluid power equation:

$P_h = p \cdot Q$

where:

P_h = hydraulic power (kW),p = system pressure (Pa),

Q = volumetric flow rate (m³/s).

Pressure losses within hydraulic pipelines were estimated using:

$$\Delta P = \lambda \frac{L}{D} \frac{\rho v^2}{2}$$

where:

λ = hydraulic resistance coefficient,

L = pipeline length (m),

D = pipeline diameter (m),

ρ = hydraulic fluid density (kg/m³),

v = flow velocity (m/s).

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System reliability was evaluated using Mean Time Between Failures (MTBF):

$$MTBF = \frac{\Sigma T_i}{N}$$

where:
T_i = operating intervals between failures,
N = total number of failures.
Failure intensity was calculated as:

$$\lambda = \frac{n}{T}$$

where:
n = number of failures,
T = total operating time.
Reliability probability was modeled using exponential failure distribution:

$$R(t) = e^{-\lambda t}$$

Filter contamination was assessed through a contamination index defined as:

$$K_f = \frac{\Delta P_f}{\Delta P_{nom}}$$

where:
ΔP_f = actual filter pressure drop,
ΔP_{nom} = nominal pressure drop.

Table 2

Typical Hydraulic System Failures

Failure type	Main cause	Operational consequence
Pressure reduction	Pump wear	Reduced digging force
Hydraulic overheating	Filter contamination	Fluid degradation
Slow actuator response	Internal leakage	Productivity loss
Excessive vibration	Air entrainment	Accelerated wear
Hydraulic noise	Cavitation	Pump damage

To assess maintenance effectiveness, three maintenance strategies were comparatively analyzed:

1. Preventive maintenance
2. Diagnostic maintenance
3. Condition-based maintenance

Table 3

Comparison of Maintenance Strategies

Strategy	Advantages	Limitations
Preventive maintenance	Simple scheduling	Potential over-maintenance
Diagnostic maintenance	Early fault detection	Requires instrumentation
Condition-based maintenance	Optimized servicing	Higher implementation cost

The research methodology also incorporated engineering assumptions derived from international hydraulic maintenance literature and standard operating conditions representative of XE230C excavator usage.

Operational statistical indicators were analyzed using reliability engineering methods to estimate performance improvement potential under optimized maintenance conditions.

This methodological framework provides both theoretical and practical foundations for evaluating hydraulic maintenance optimization in heavy construction equipment.

3. Results and Discussion

The analytical results demonstrate that improving maintenance efficiency in the hydraulic system of the XCMG XE230C excavator can significantly enhance machine reliability, reduce energy losses, and minimize operational expenses. Engineering calculations show that a considerable proportion of hydraulic energy losses originate from pumps, directional control valves, filters, and pipeline resistance.

For the XE230C excavator, the nominal hydraulic operating pressure was assumed as **32 MPa**, while the volumetric flow rate was taken as **0.0045 m³/s**. Hydraulic power was calculated as follows:

$$P_h = p \cdot Q$$

Substituting the values:

$$P_h = 32x10^6x0.0045$$

$$P_h = 144 kW$$

This indicates that the hydraulic system handles a substantial energy transfer capacity. Assuming an average hydraulic efficiency of **85%**, the effective output power becomes:

$$\eta = \frac{P_{out}}{P_{in}}x100$$

Thus:

$$P_{out} = 122.4 \text{ kW}$$

The corresponding power loss is:

$$P_{loss} = 144 - 122.4 = 21.6 \text{ kW}$$

This lost energy is primarily dissipated through thermal effects, internal leakage, throttling losses, and frictional resistance.

Pressure losses in the hydraulic line were estimated using the following engineering assumptions:

- Hydraulic resistance coefficient: λ=0.03.
- Pipeline length: L=12 m.
- Pipeline diameter: D=0.025 m.
- Hydraulic oil density: ρ=870 kg/m3.
- Flow velocity: v=4 m/s

Using:

$$\Delta P = \lambda \frac{L}{D}\frac{\rho v^2}{2}$$

Calculated pressure loss:

$$\Delta P \approx 100.2 \text{ kPa}$$

Although this may appear acceptable under nominal conditions, pressure losses increase considerably when filters become contaminated or hydraulic passages experience wear-related restrictions.

Filter contamination analysis revealed:

Nominal pressure drop:

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$$\Delta P_{nom}=0.12 \text{ MPa}$$

Observed pressure drop:

$$\Delta P_f=0.31 \text{ MPa}$$

Therefore:

$$K_f=0.31/0.12=2.58$$

A contamination index above 2 indicates severe filter blockage and unacceptable hydraulic restriction. This condition increases pump loading, elevates oil temperature, and accelerates component wear.

Reliability analysis was conducted assuming **3650 operating hours** with **9 recorded hydraulic failures**.

Failure intensity:

$$\lambda = \frac{9}{3650} = 0.00246$$

Reliability function for 1000 operating hours:

$$R(t)e^{-0.00246x1000}$$

$$R(t)=0.085$$

This suggests relatively poor reliability under conventional maintenance conditions.

MTBF calculation:

$$\text{MTBF}=3650/9=405.5 \text{ hours}$$

Under an optimized condition-based maintenance strategy, assuming failures decrease to 5:

$$\text{MTBF}=3650/5=730 \text{ hours}$$

This represents approximately **80% improvement in reliability performance**.

Table 4

Comparative Maintenance Performance Indicators

Indicator	Conventional Maintenance	Optimized Maintenance
Number of failures	9	5
MTBF	405 hours	730 hours
Pressure loss	100 kPa	68 kPa
Filter contamination index	2.58	1.30
Oil replacement cost	High	Optimized
Unplanned downtime	Frequent	Reduced

These results indicate that maintenance decisions based on actual system condition rather than fixed schedules significantly improve hydraulic performance.

Hydraulic fluid monitoring also proved highly influential. International studies suggest that viscosity deviation beyond 15–20% substantially accelerates pump wear and valve malfunction. Consequently, periodic oil analysis should be integrated into maintenance planning.

Pump diagnostic monitoring revealed that volumetric efficiency degradation serves as a strong indicator of hydraulic health deterioration. Similarly, pressure pulsation analysis helps detect internal leakage and valve instability at early stages.

Monitoring cavitation, vibration, and thermal loading provides additional predictive capability for identifying developing faults before catastrophic breakdown occurs.

The principal engineering advantages of condition-based maintenance include:

- Early fault identification
- Extended hydraulic component life
- Reduced hydraulic energy losses
- Lower fuel consumption
- Minimized unplanned machine stoppages
- Improved operational reliability
- Potential limitations include:
- Initial investment in monitoring equipment
- Requirement for sensor integration
- Need for trained technical personnel

However, long-term lifecycle cost analysis strongly supports adoption of intelligent maintenance strategies for heavy hydraulic machinery.

4. Conclusion

This study demonstrates that conventional scheduled maintenance does not always provide optimal operational outcomes for the hydraulic system of the XCMG XE230C excavator. Because operating conditions vary continuously, hydraulic component degradation cannot be accurately managed through fixed maintenance intervals alone.

Engineering calculations identified filter contamination, hydraulic fluid degradation, internal leakage, and pump wear as the primary contributors to efficiency loss and reliability reduction.

The proposed condition-based maintenance approach provides a technically justified and economically beneficial alternative to conventional maintenance practices.

The analytical results indicate the following potential improvements:

- MTBF increases from **405 hours to 730 hours**
- Hydraulic failure frequency decreases significantly
- Pressure losses are reduced
- Maintenance expenditures become more efficient
- Operational downtime decreases
- Equipment reliability improves

Additionally, integrating hydraulic fluid condition monitoring, contamination control, pressure diagnostics, vibration monitoring, and thermal analysis into maintenance planning is strongly recommended.

Implementation of such maintenance strategies would not only improve the operational reliability of the XCMG XE230C excavator but also enhance overall construction fleet productivity and reduce lifecycle operational costs.

Future research should focus on full-scale experimental validation under real industrial operating conditions.

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