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Only original and written in English works are published, which represent both theoretical and applied sciences. All papers are reviewed by two independent referees.

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Diagnostic models of hydraulic systems in agricultural and construction machines

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Abstract

The paper presents functional and exploitation characteristics of hydraulic system elements of working machines[1] orientated on fault detection. Identification of diagnostic model of hydraulic system orientated on the fault detection models has been carried out.

Keywords: Working machines; Diagnostic model; Hydraulic systems

Nomenclature

p	–	throttling pressure, Pa	y_i	–	checking set of elements
q	–	leakage intensity, cm^3/s	(Y_A^n)	–	fault isolation algorithm
t	–	piston rod movement time, s	(Y_A^S)	–	state checking algorithm
v	–	speed of piston rod movement, m/s			

1 Introduction

The world wide development of agricultural and construction machines and earth movers induces significant changes in the control and adjustment of their working mechanisms. These changes are accompanied by fundamental changes in the realisation of transmission, control and automatic systems.

For the recent several years the tendency has been observed to apply a higher pressure, a greater intensity of flows and the increase in flow speed through the

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[1]Working machines = agricultural and construction machines and earth movers

element in the power hydraulic systems [3]. This tendency results from the designer aspiration to limiting the overall dimension of the hydraulic elements with assuring at the same time, their greater specific powers. This phenomena required necessity decreasing the backlash in the mating kinematic pairs. The exemplary range of the average fluid clearances in the typical hydraulic elements is within 1 μm to 25 μm (gear pumps, distribution spool valves).

Most of the researches of hydraulic systems are aiming optimisation of their elements, among other things, in the scope of minimal overall dimensions (decreasing volume and mass), energy consumption (minimal pipe resistance), decreasing of the production costs, increasing serviceability and working reliability. Studies on the dynamic problems, which could lead to the development of defects of the hydraulic elements, have been carrying out in a relatively small extent [1].

Study of system dynamics, by applying different forced input signals and variable loading, enables to recognise a poorly known phenomena that can occur during testing of new designed hydraulic systems.

Those complex researches of hydraulic systems in agricultural and construction machines and their transient states are the source of new diagnostic information necessary in evaluation of the reliability states [5].

2 Functional and operating characteristics

Components of hydraulic systems perform their functions in variable physical conditions, which result in the change of their features, conditioning their proper work and their durability. It has been estimated that above 90% of damages of the mating tribological pairs in the hydraulic elements result from the abrasive wear by solid particles of contamination within the 1-15 μm dimensions range, [8]. The carried out exploitation researches on hydraulic systems indicate that the most frequent damages occurring in the following units, [4]:

- hydraulic cylinders $\sim$ 35÷40%;
- pumps $\sim$ 35÷40%;
- hoses $\sim$ 10÷15%;
- distribution spool valves $\sim$ 15.

The solid contamination and the wear products of mating elements penetrate into the systems because of the working fluid continuous flow. At the same time it results in changing the working fluid property, which functions as a lubricating layer. These hard solid particles of the contamination in the lubricating layer produce intense wear of the mating surfaces.

Figure 1 shows a typical wear forms in some tribological pairs in hydraulic systems and the behaviour of the hard solid particles in the slots between mating elements.

As shown in Fig. 1a, contamination particles can cause a seizure of the

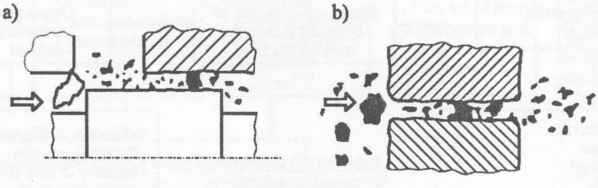

Figure 1. A typical wear forms of some tribological pairs in the hydraulic systems; a – slot of the distribution spool valve, b – slot of the hydraulic cylinders.

spool in the housing, damages of the edge or working surface. Fig. 1b shows that the most dangerous are particles with dimensions close to the value of clearance (distances between mating surfaces). The smaller is that clearance, the more vulnerable to damages caused by small particles is the element of the hydraulic system.

The quantitative level of contamination in the working fluid allows to assign the cleanness classes according to NAS 1638 and ISO-DIS 4406 standards. These standards define a number of solid particles in 100 ml of working fluid dependant on assumed granular structure of particles (groups of dimensional quantity) [in μm].

The findings [1] indicate that the fresh hydraulic oil has been classified in the 9-10 cleanness class according to NAS 1638 and oils that were operated in different working machines are placed in the range of 12 cleanness class (or out of that range). The wearing process and service life depends on the cleanness of the elements as well as preliminary and exploitation filtering of working fluid.

3 Identification of diagnostic models

A diagnostic model of the hydraulic system can be presented in a cybernetic formulation where the inlet are: supply, control and environment interactions, whereas the outlet: working processes and residual processes that are, considering the diagnostic conditioning, treated as diagnostic symptoms and signals. A general diagnostic model diagram of the hydraulic system of the working machine is shown in Fig. 2.

The diagnostic model of a hydraulic system includes relationships (R) between reliability states $S(x,t)$ and observed symptoms (Y) as well as diagnostic signals $Y(t)$

$$R : S(x,t) \rightarrow Y \cup Y(t).$$

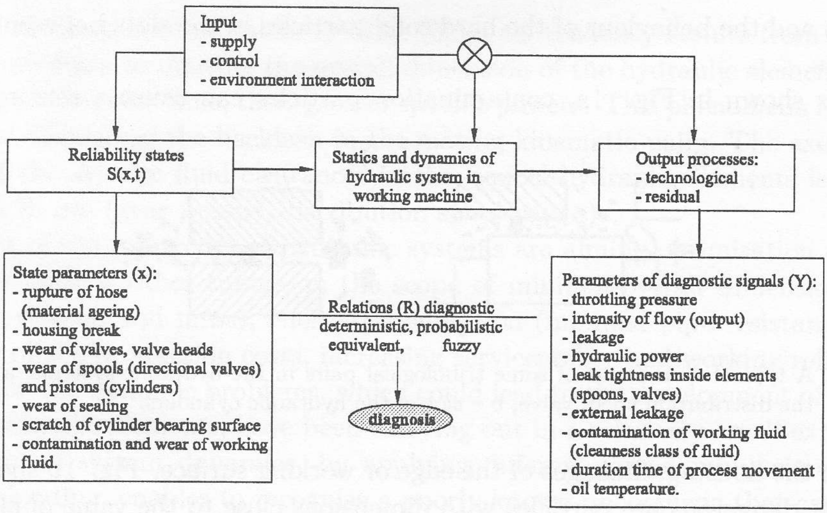

Figure 2. Diagram of a diagnostic model of the hydraulic system of a working machine.

In this situation the diagnostic concluding at the time t might be presented as a function of a state vector and a diagnostic signal vector. In order to formulate the diagnose about the state of a hydraulic system the diagnostic information is necessary, which can be obtained on the basis of a checking set Y of the diagnostic parameters

$$y_n \in Y, n = \overline{1, N},$$

where y_n – available number of checking of the diagnostic parameters.

From the Y checking set, as the result of choosing y_n, several sets of checking can be formulated, which are different in power (in number of elements), combination and sequence of checking of the hydraulic system elements.

On the basis of an ordered, minimal set of diagnostic checking the diagnostic algorithm Y_A can be generated

$$Y_A = y_i, i = \overline{1, I}$$

where $y_i \leq y_n$.

There are state checking (Y_A^S) and fault isolation (Y_A^n) algorithms. A general diagram of generating of a diagnostic model of hydraulic system is presented in Fig. 3.

Determination of the system element set and their reliability characteristics set form the basis for a development of a diagnostic model. Then, basing on determination of the state characteristics and corresponding diagnostic parameters, a procedure of diagnostic checking can be elaborated [6].

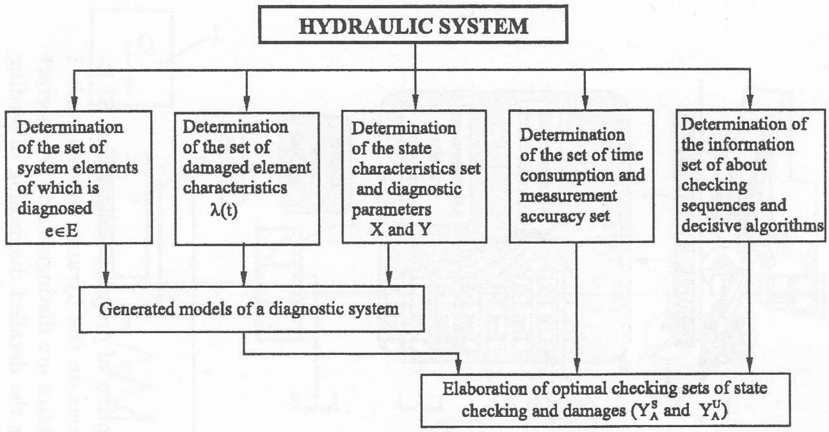

Figure 3. Diagram of a diagnostic model formulation.

Therefore identification of a diagnostic model of hydraulic system can be expressed by the following points

- determination of functional and reliability characteristics of elements;
- selection of independent parameters of reliability states of a system;
- selection of diagnostic parameters for determination of the states of the system;
- determination of boundary values of the state and diagnostic parameters;
- determination of the diagnostic model structure.

The simulation research: the speed of piston rod movement in dependence of the pump leakage. Fig. 5 presents the testing stand.

The speed of piston rod movement dependence on the simulating intensity of leakage is shown in Tab. 1 and Fig. 6, [5]. Figure 7 shows the flow intensity as a function of the throttling pressure of the gear pump in hydraulic system of grain combine harvester. On the research stands [3] the course of pressure in supply conduit to the cylinder in the working circle (Fig. 8) has been determined. In Fig. 8 the course of pressure, where the maximal impulse of pressure exceed the value setting of the safety valve, has been shown.

4 Summary

Basing on the theoretical considerations and experimental investigations it can be stated that for contemporary hydraulic systems in the working machines the following conclusions can be drawn:

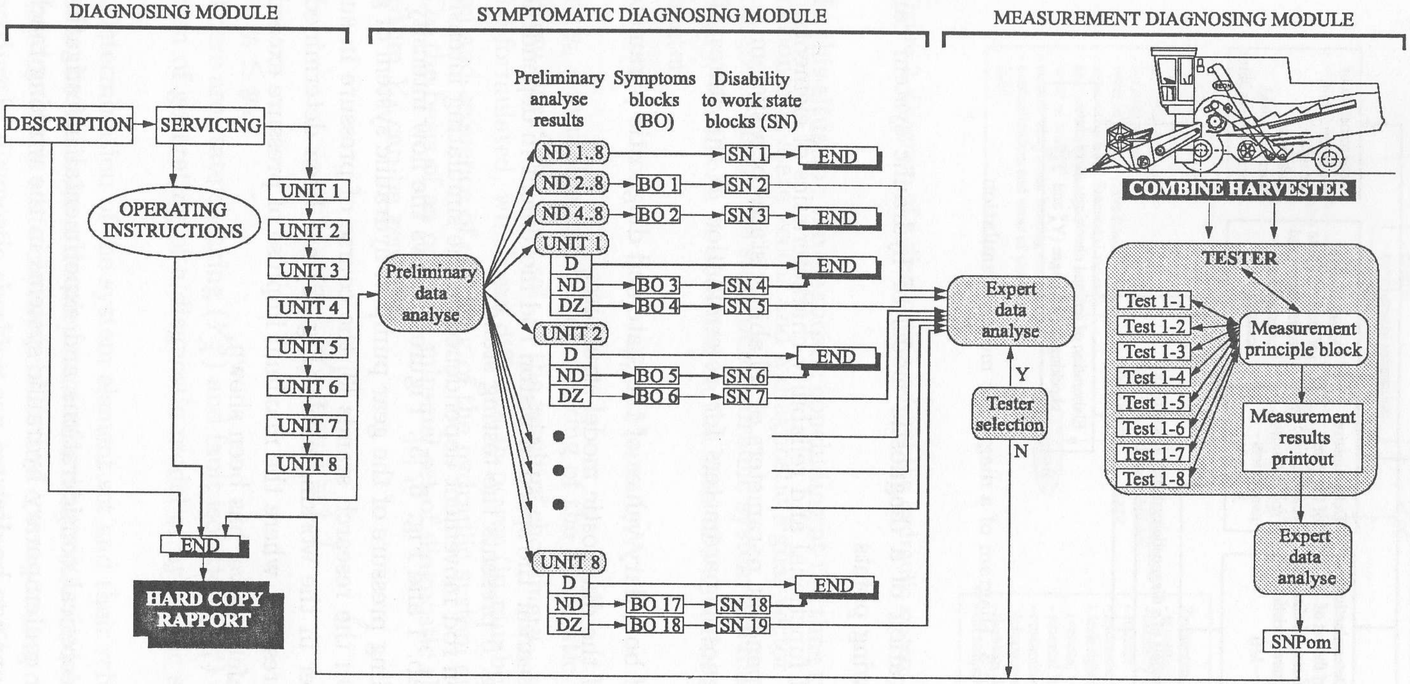

Figure. 4. Diagnostic algorithm of a combined-harvester hydraulic system: DESCRIPTION – description of program assignation, SERVICE – data acquisition bloc. Acquisition data about performed service and repair actions on the hyraulic system; unit 1 ...unit 8 – bloc of questions about functioning particular subunits for that the following states are distinguished: D – correct action, ND – no action, DZ – faulty action, BO 1...BO 18 – blocks of symptoms enabling the detailed diagnosing of feeding elements, control-adjusting and executory elements formulated with the assistance of the base table, SN 1...SN 19 – blocs of the symptomatic diagnosing disability states, SNPo – blocks of the measurement diagnosing disability states, Test 1-1...Test 1-8 – measurement tests of the subunits of hydraulic system.

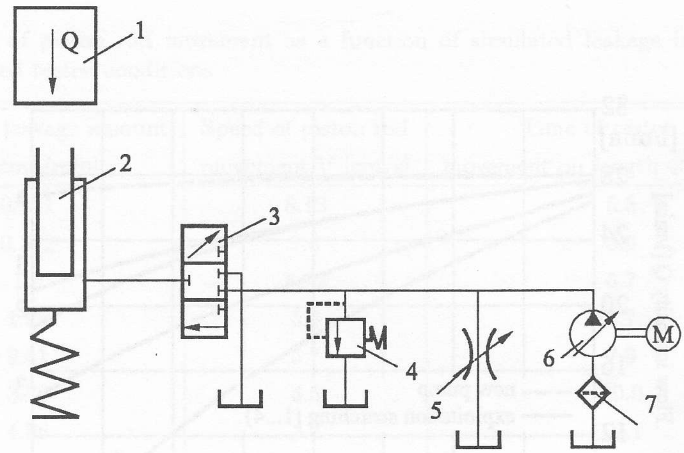

Figure 5. Diagram of arrangement for simulation research: 1 – mass-balance 10 kN, 2 – hydraulic cylinder for header lifting, 3 – hydraulic selector valve, 4 – safety valve, 5 – control valve for leakage simulation, 6 – gear pump, 7 – filter.

- developed diagnostic models, taking into consideration the contamination concentration in the oil and the wear pattern of the tribological pairs in the hydraulic system elements,
- assumed new diagnostic parameters based on dynamic indicators determined in transient states, among others the maximum instantaneous pressure impulse in the supply conduits (in working cycle of an element), oscillatory susceptibility, dynamic load factors, starting up and breaking times,
- developed diagnostic expert systems orientated on fault detection and different diagnostic, probabilistic and fussy relation forms.

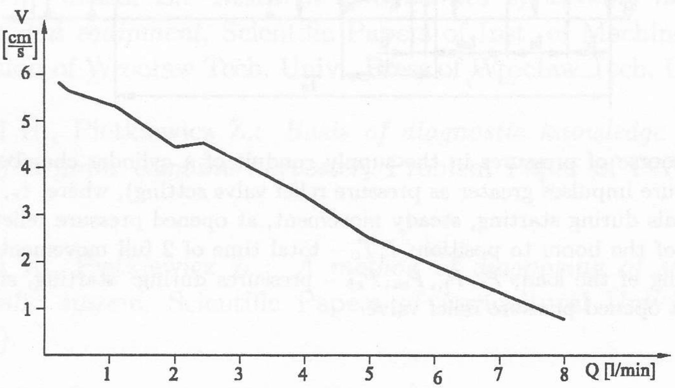

Figure 6. The speed of lifting of reel as a function of the leakage intensity of the gear pump.

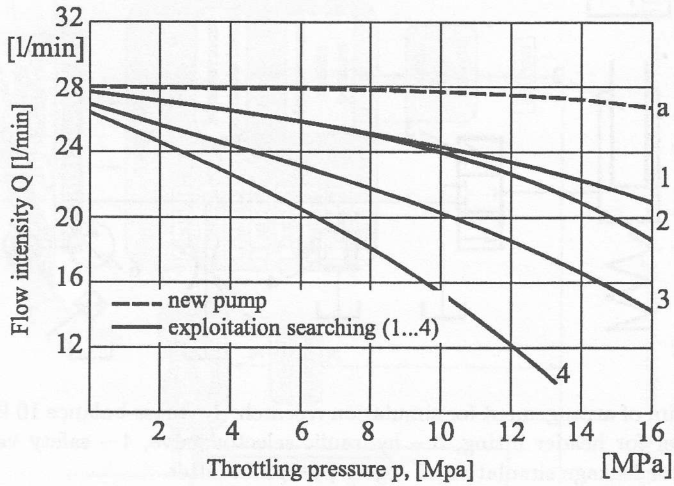

Figure 7. The flow intensity as function of the throttling pressure of the gear pump in the hydraulic system of a grain combined harvester.

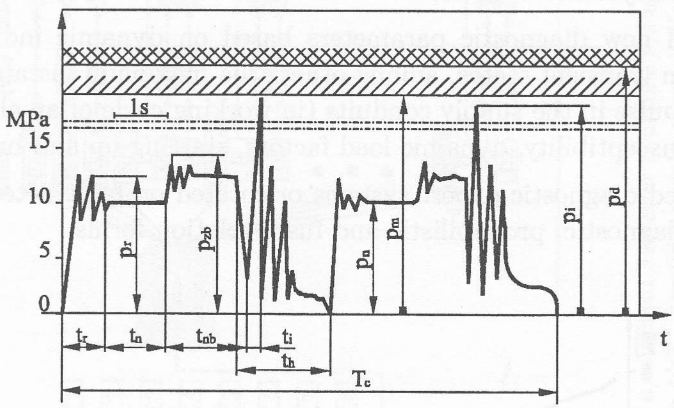

Figure 8. The course of pressures in the supply conduit of a cylinder chamber of mechanism (pressure impulses greater as pressure relief valve setting), where: t_r, t_n, t_{zb}, t_h – time intervals during starting, steady movement, at opened pressure relief valve and lowering of the boom to position; I, T_c – total time of 2 full movements at raising and lowering of the load; P_r, P_n, P_m, P_{zb} – pressures during: starting, steady movement and at opened pressure relief valve.

Table 1. Speed of piston rod movement as a function of simulated leakage intensity for the assumed tested conditions

Simulated leakage amount q [dcm^3/min]	Speed of piston rod movement V [cm/s]	Time of piston rod movement on length 450 mm t [s]
0.141	8.13	5.5
0.372	7.6	5.9
1.0	6.72	6.7
1.98	5.8	7.7
2.41	5.7	7.9
3.79	4.5	10.0
4.86	3.7	12.1
8.04	0.7	64.3

Pump rotational speed: – 500 r.p.m. $p = 5$ MPa($Q =$ const)
Stroke = 630 mm Temp. t = 30°C
Piston rod diameter $d = 50$ mm

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