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An Application of the Systematic Diagram in the Failure and Causes Analysis of a Vane Pump

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Abstract. Hydraulic systems are widely spread among drive and control systems. They can play a crucial role in many applications; therefore, identifying potential failures and their causes might be required. Quality improvement tools and methods can be used to achieve this goal. This research attempts to apply one of the recently developed tools, which is a systematic diagram, to recognize possible failures and their causes and finally to define preventive measures for a typical hydraulic vane pump. The analysis of potential pump failures and their causes identified oil contamination as the primary source of pump failure or malfunction. Consequently, proper maintenance was found to be the proper preventive measure.

Introduction

Hydraulic systems, due to their advantages, are one of the top-rated drive systems in various industries, from agriculture, heavy machinery, mining, oil, and gas to the aerospace industry. Components of hydraulic systems have complex electro-hydro-mechanical structures. The most substantial and complicated structures among them are hydraulic pumps. Their main task is to convert mechanical energy into pressure energy and provide the required fluid flow rate. There are several main types of hydraulic pumps, such as gear, screw, piston, or vane. Regardless of the type, they might be one of the most expensive components in the system, and their failure might be catastrophic for the whole system. Therefore, it is crucial to identify symptoms of potential failures to take appropriate measures at an early stage of their occurrence or even during system design. In order to identify possible failures during operation, various diagnostic systems can be used. In contrast, quality improvement methods find application before the system is implemented. The most popular methods are Failure Modes and Effect Analysis (FMEA) [1-3], Quality Function Deployment (QFD), or methods using experimental data in designing products and processes. The abovementioned methods can be supported by quality improvement tools at various stages of their implementation. Those tools are used for collecting and processing data related to various quality aspects. They are instruments for monitoring and diagnosing design, manufacturing, control, or assembly processes throughout the product life cycle. These tools allow collecting information to define Total Quality Management (TQM) actions. Among the quality control tools, we can find the classical quality improvements tools such as the Ishikawa diagram, Pareto analysis, or correlation diagram. The "new" quality improvement tools are relationship diagrams or systematics diagrams [4,5]. The application of those tools is more and more extensive, particularly in the automotive industry. This paper attempts to implement a systematic diagram to identify the causes of potential failures of a vane pump.

Analogous methods for enhancing quality based on the development of potential failure scenarios are widely employed in the industry [6-8]. These methods allow for the optimization of preventive measures, minimizing them to the necessary minimum in line with lean principles [9,10]. This approach is particularly critical in the production of highly responsible products, such as in the machinery [11,12], railway [13], hydraulic power [14], and military [15-17] sectors.

Technological advancements play a significant role in improving reliability in these industries. This includes the selection of appropriate materials [18], their precise processing [19-21], and the shaping of desired functional characteristics in cooperating surface layers [22-24]. By implementing these techniques, several benefits are achieved. First, the corrosion resistance is significantly enhanced [25-27], leading to increased durability and longevity of the products. Second, the wear and tear rates during operation are reduced, resulting in prolonged lifespan and improved performance [28-30]. Lastly, the strength of welded joints is improved, ensuring structural integrity and safety [31-33].

An additional positive consequence of these improvements is the overall increase in product quality [34-37]. This has a direct impact on reducing the strain on the natural environment, contributing to sustainability efforts [38]. Moreover, these advancements inspire the application of image analysis methods for the identification and analysis of coating and surface layer characteristics [39,40]. By leveraging image analysis techniques, researchers and engineers can gain valuable insights into the performance and properties of surface coatings, facilitating further optimization and refinement of the manufacturing processes.

Design and Functionality of a Vane Pump

A vane pump is the positive displacement pump type. Its main features are high efficiency and reliability. An additional advantage is the low noise emission during operation and low operating costs. An example of the vane pump is presented in Fig.1. It has a relatively simple structure, where vanes are placed in a rotor socket and expanded to the stator during rotation, creating a pumping chamber [41]. Failure-free pump operation requires hydraulic oil to fulfill specific requirements for cleanliness, contamination level, and self-lubricating capability. The available research indicates that the cause of the majority of vane pump failures is improper operational conditions [42]. The knowledge about the causes of pump failures allows for defining preventive or/and corrective measures.

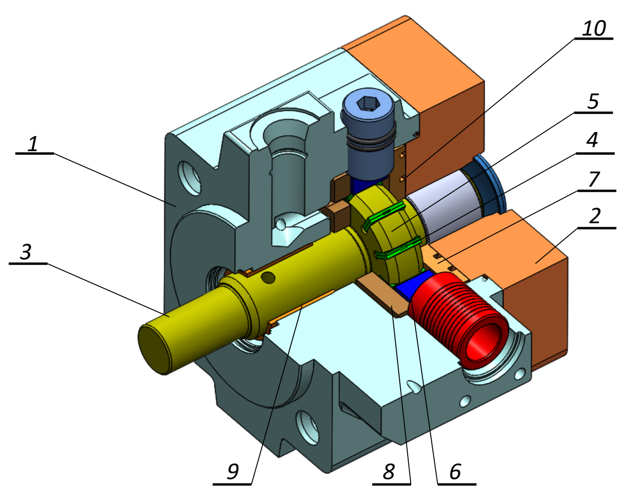

Fig.1. *Hydraulic vane pump (UPLV 32 type), where: 1 – pump body, 2 – cover, 3 – shaft, 4 – vanes, 5 – rotor, 6 – stator, 7,8 – plates, 9 – sleeve, 10 – plate sealings.*

Systematic Diagram

The Flow/Systematic diagram is one of the decent quality improvement tools known as a tree diagram or decision tree. It is most often used during the planning and managing processes in the organization to anticipate the consequences of decisions taken. It can also be used during concept development and the design of new products to identify possible failures or improvement actions for identified problems. It has a graphical form for presenting the ordering activities necessary for a given process or factors influencing the occurrence of a given failure. The diagram systematizes the causes of the problem in a chronological and logical order following the principle "*from general to detail*".

Furthermore, it can be used to arrange information in a relationship or dependency charts [43,44]. The main idea of the systematic diagram refers to the tree diagram, thanks to which it is possible to use specific techniques helpful in its preparation. One of these techniques is a systematic functional chart based on the FAST technique [45]. The procedure for developing a systematic diagram includes five steps:

– stage 1 – level 0: defining the problem/effect (marked 000),
– stage 2 – level 1: determining the main categories of causes for a given problem/effect (designation I00, II00),
– stage 3 – level 2: determination of causes for a given effect (designation I10, II10)
– stage 4 – level 3…n: determination of sub-causes for a given cause (designation I1a, II1a)
– stage 5 – selection the cause that has the greatest impact on the problem/effect.

In the above-presented procedure, the systematic diagram logically presents cause and effect relationships for the problem/effect under consideration. Fig. 2 shows an example of a systematic diagram. The diagram is constructed from the general (left) to the detail (right).

The result of the analysis of the systematic diagram should be the determination of the leading cause category and the main cause that has the highest impact on the effect/problem. In the next step, the appropriate corrective measures should be specified so that the identified problem is resolved and there are no severe consequences due to its negligence.

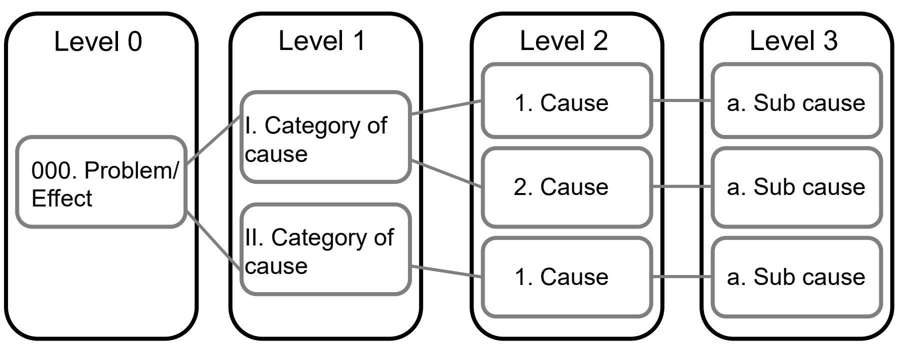

Fig.2. *A graphical representation of the systematic diagram*

Systematic Diagram in Failure Analysis of a Vane Pump

The operation of a vane pump is based on converting mechanical energy into the pressure energy of the working fluid. The failures that can occur during operation might cause pump malfunction or inability to operate. Some of those failures can be fixed directly onsite. The others may require sophisticated equipment or even component replacement. Therefore, the identification of the possible failure causes is a principal issue. This can be realized by a systematic diagram which is presented in Fig. 3. The diagram includes three main categories of failure causes: operation, design, and assembly/repair. For each of them, the causes that can be a potential source of the failure are specified. Consequently, the three sub-causes were assigned for each of them.

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According to the literature review [42], the highest probability of failure of vane pumps arises during maintenance errors (I), which degrades the working fluid (I1a-d). Maintaining an appropriate quality of hydraulic oil is the primary cause affecting the proper operation of the vane pump and the entire hydraulic system. A change in the color of the working liquid indicates its property degradation or the initiation of contamination. Therefore, in the second step of the analysis, the systematic diagram was used to identify possible causes of failures of the vane pump during its operation, as presented in Fig.4.

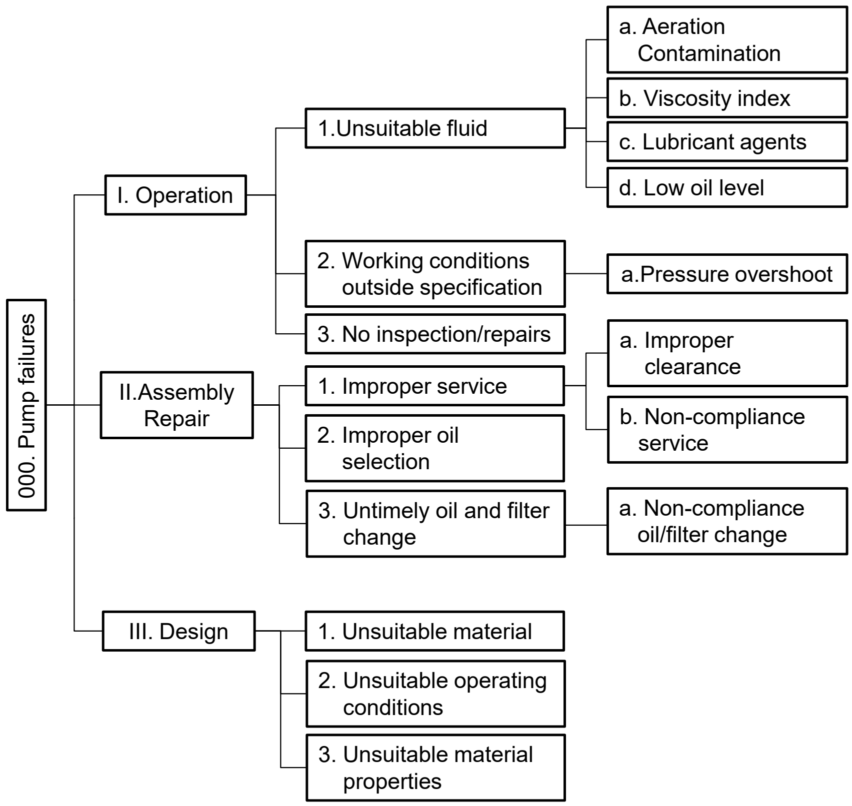

Fig.3. *A general systematic diagram of causes of vane pump failures*

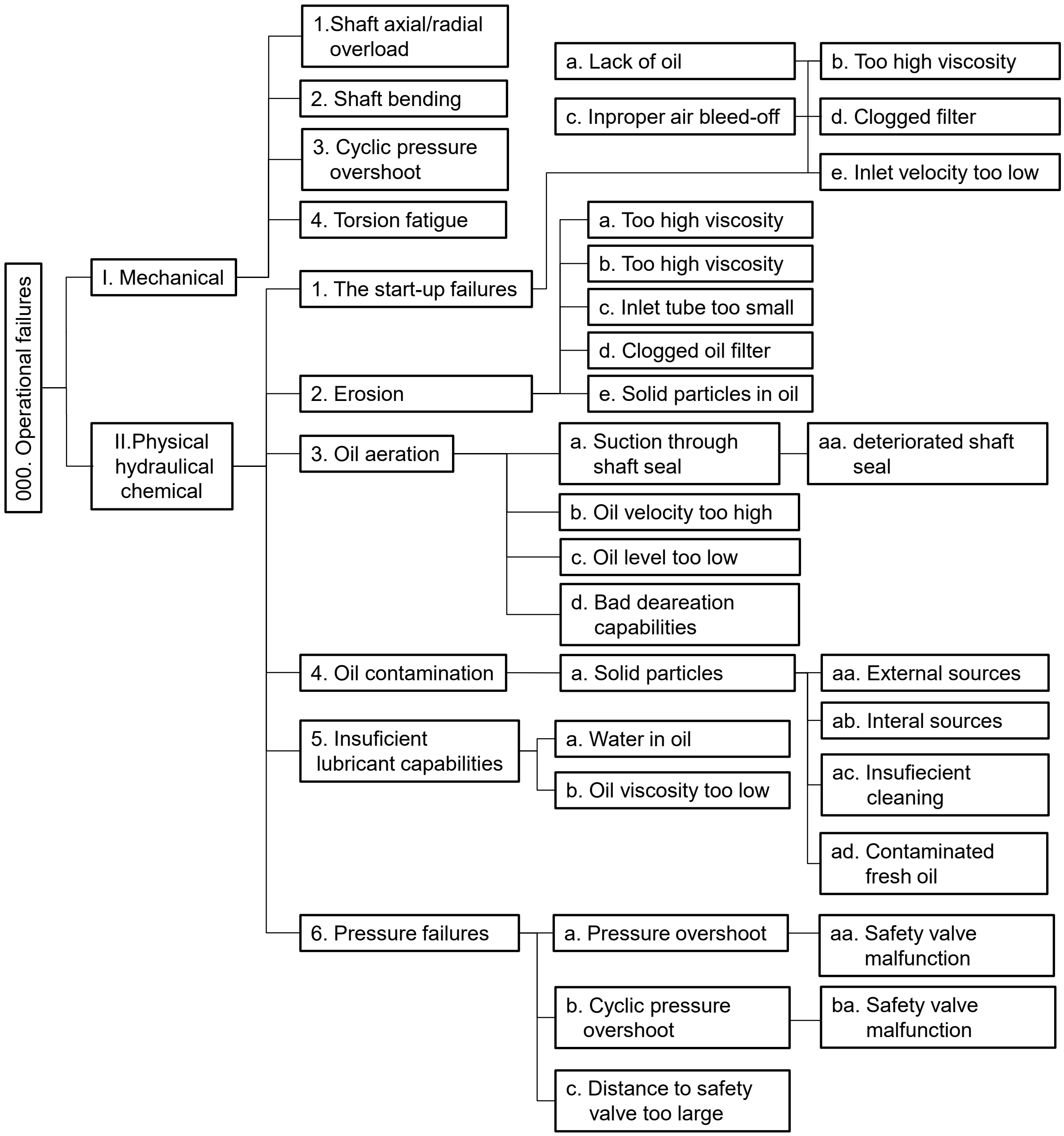

Fig.4. *A detailed systematic diagram for identification of vane pump failures*

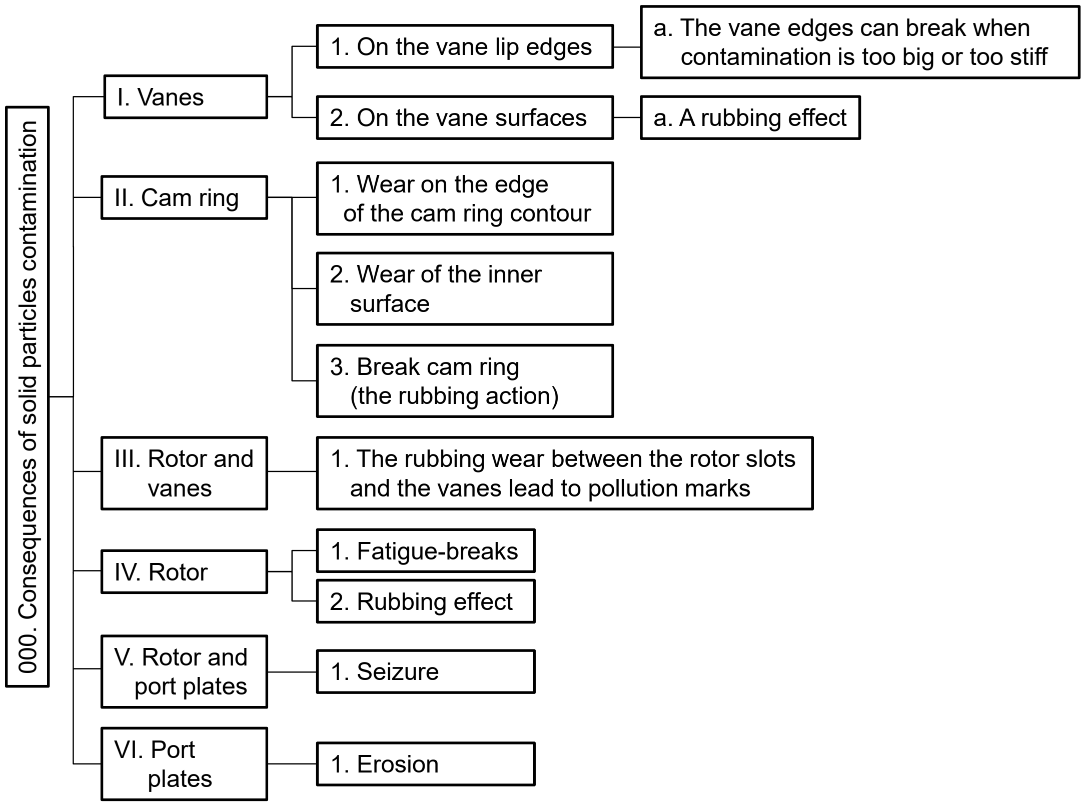

Fig.5. *The systematic diagram for effects of solid particles contamination*

The systematic diagram shows that maintenance errors are the sources of the vane pump failures. The most common errors are ineffective deaeration at the pump start-up, starting an operation without oil, or using oil with too high viscosity. Another related problem is cavitation, which may cause erosion and surface degradation. A widespread oil failure is the oil aeration caused by insufficient seals in the suction line or pump shaft. Dissolved air in oil affects oil properties, changes compressibility, disturbs the cooling and lubricating process, and, in the worst scenario, may cause pump components to be seized. The other typical oil contaminant is water which converts working fluid into a mixture with lower lubrication capabilities and viscosity. Under high pressure, such a mixture forms foam, significantly decreasing oil bulk modulus and disrupting proper vane operation. At this analysis stage, two main categories of causes were distinguished: I. mechanical and II. physical, hydraulic and chemical. Then, within these two categories, a total of 10 causes and 20 sub-causes were identified. The leading cause of the failure of the vane pump appeared to be contamination of oil with solid particles. It may cause cavitation corrosion (erosion), scratches on the surfaces of the pump components, and fluctuation in the pump operation. Oil contaminated with solid particles may also affect the entire hydraulic system and lead to faulty operation. In the last step of the pump failure analysis, the systematics diagram presented in Fig. 5 was created on which the consequences of solid particle contamination were presented [42].

A contaminated oil with solid particles and water may cause noisy operation, destruction of components, or excessive wear. Measures presented in Table 1 can be undertaken to prevent the failures caused by contaminated fluid.

Table 1. *Preventing measures for contaminated oil*

Cause	Symptom	Measures
Contaminated fluid	Noisy operation	Install an adequate filter or replace the oil more often. Determine source of contaminants and correct
	Breakage of parts inside the pump housing	
	excessive wear	

Conclusions

The implementation of a systematic diagram for vane pumps failure analysis allowed for identifying the causes of the most common failures. Regardless of the durability of pump components, it is very sensitive to the quality of working fluid. Presented in this research analysis indicates that oil contaminants are the significant sources of pump malfunction. They degrade oil properties, which may lead to pump malfunction or even inability to operate due to component destruction. Therefore, adequate maintenance procedures are key to the failure-free operation. Obtained results agree with other research, which defines oil as main source of failure for fluid power systems.

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