ANALYSIS OF THE METHODS FOR ASSESSING THE RELIABILITY OF SPOTWELDING MACHINES IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT
In the present time, the manufacturing processes are becoming complex and the transition from mass production to lean production sets to the manufacturer high standards of quality and reliability. As a consequence, the requirements for equipment reliability is getting higher. Therefore, it is becoming a difficult task to the plant workforce to choose an appropriate maintenance policy and spare parts strategy. In this case, properly constructed diagnostic system and system reliability calculation would be very useful for designers and plant managers to significantly reduce the number of unnecessary tests and hence reducing the associated costs. To achieve higher reliability and high quality of the products, the manufacturing companies should implement predictive and analytic algorithms by means of software and applying them to existing maintenance processes.

Keywords: Reliability; Maintainability; Proportional Hazard Model; Markov Chain; Operational Environment, Influential Factors

INTRODUCTION
Projection spot welding (PSW) machines are mainly used in the automotive industry for welding car bodies where high quality welds are required as well as high system reliability [1]. A modern car contains up to 3000-5000 welding points, produced on a PSW machine. Welding joints are located in critical parts of the machine body, the poor quality of which can lead to high financial costs or risks related to the safety and life of the passenger. Therefore, the strength of the spot weld is extremely important for the durability and safety of the vehicle structure [2]. Quality and safety standards such as MVSS (Automotive Safety Standard) and ISO 9000 focus on the quality of automotive welds, requiring strict control of welding processes by manufacturers.

In most cases, the quality of welded joints depends on the efficient operation of the welding machine and its components [3]. In this regard, ensuring the reliable and efficient operation of the apparatus is necessary to comply with the established requirements for the quality of welding. The problem of maintaining the efficient operation of equipment in the automotive industry can be successfully solved by analyzing the reliability and maintainability of its operation [4]. Compliance with the requirements for work equipment and manufactured products can be achieved by analyzing the reliability of the equipment. This analysis identifies a weak point in the system, establishes appropriate maintenance scheduling intervals, and identifies and articulates reliability requirements in relation to specified operating conditions. Reliability analysis has been successfully used as a reliability design method over the past decades. From being a subject for academic researchers, it has grown to a set of well-developed methodologies with a wide range of practical methods [5]. Various methods of reliability analysis include: Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Reliability Block Diagram (RBD), Availability and Maintainability Analysis (RAM), Monte Carlo and Markov Chains, which are often used in the literature to analyze the reliability of various types of systems and equipment. Methods for ensuring the reliability of a welding machine, which can be easily applied in an industrial environment, have not yet been presented in the literature. However, the application of the analysis of the reliability of the welding process of various welding machines (specific) components has been presented by several authors [6], [7], [8]. All of them are based on the theory of probability and quantitative indicators of reliability. At present, both in theory and in practice of reliability, the use of the probabilistic method for complex systems to obtain indicators of reliability and availability has proven its relevance [9]. [10] An analytical probabilistic model has been developed for an automated system with an n-machine in a series. The model was applied to investigate the effect of system parameters on system performance on a croissant production line. [11] presented a model for the availability of forging press systems based on a probabilistic approach. Using the Markov model, the probabilities of the system and subsystems were analyzed. One of the main goals of this method is to improve the reliability and maintainability of the system through timely preventive maintenance. Preventive maintenance is a type of maintenance aimed at preventing or predicting failure before the complete failure of the system [12]. The process of predicting (predicting) preventive maintenance is a process that determines the technical condition of a system and its components based on monitoring equipment failures and repair modes over a certain period of time. The failure and repair behavior of RSWS has a random process. The most powerful and widely used method for analyzing and predicting random processes in the theory of reliability is the Markov process [13]. The Markov process can analytically describe the random processes of the technical state of the PSW machine.

To analyze and establish the PSW service strategy, we examine Markov modeling techniques. The degradation process of the system and the predictions of failures will be analyzed using a homogeneous Markov chain that is continuous in time. Information on system failures and repairs will be further examined to identify the relationship between system deterioration and product quality. A Markov model has been developed to analyze the reliability, availability and maintainability of the PSW machine. Further, based on the estimated indicators, the effectiveness of the entire process is analyzed. We also performed an analytical and numerical analysis of the PSW machine in a stochastic framework. Appropriate maintenance strategies that match the technical condition of the PSW machine and the mode of operation are established.

Maintenance Strategies in the Automotive Industry

The productivity of the production process is highly dependent on a reliable system. Degradation of the system can lead to high operating costs and reduced product quality. In the automotive industry, producing high quality products is a must. Reactive Maintenance (RM), Preventive or Scheduled Maintenance (PM), Condition Based Maintenance (CBM), Reliability Based Maintenance (RCM), Predictive Maintenance (PM) are used to maintain the stability of the production process and maintain good quality.

Reactive Maintenance (RM)

Reactive maintenance is used in situations where the failure is not critical and has little risk to the production process. Also known as corrective maintenance, it is basically an attempt to restore a system to a working condition. RM is still used in maintenance programs because in the complexities of modern car manufacturing it is still difficult to accurately predict failure.

Condition Based Maintenance (CBM)

CBM includes maintenance that is scheduled based on monitoring information. This maintenance strategy monitors the actual state of the system and decides what maintenance needs to be performed. CBM indicates that maintenance should only be performed when the system indicates signs of deterioration or impending failure. If in PM, maintenance is performed based on certain scheduling intervals, CBM is performed when systems signal that the PM needs to be rescheduled. This is the ideal PM type and is planned based on the actual state of the system.

Reliability-oriented maintenance (RCM)

RCM is a type of service strategy that determines the most efficient approach to service. The RCM philosophy uses many tools such as predictive maintenance (PM), predictive maintenance (PM), real-time monitoring (RTM) to analyze the maintenance strategy that will be used in the manufacturing process. Other tools for analyzing a suitable service process. Failure Modes and Effects Analysis, Probability Methods, Statistical Methods - SPC included. Service strategies are optimized and analyzed using these techniques. The main philosophy of RCM is to provide the necessary reliability and availability at the lowest cost [14]. RCM requires that a maintenance decision be based on maintenance requirements and justified economically. The basic structure of the RCM is shown in Figure 1-1. RCM's solution is based on four categories: latent safety failures and environmental consequences.

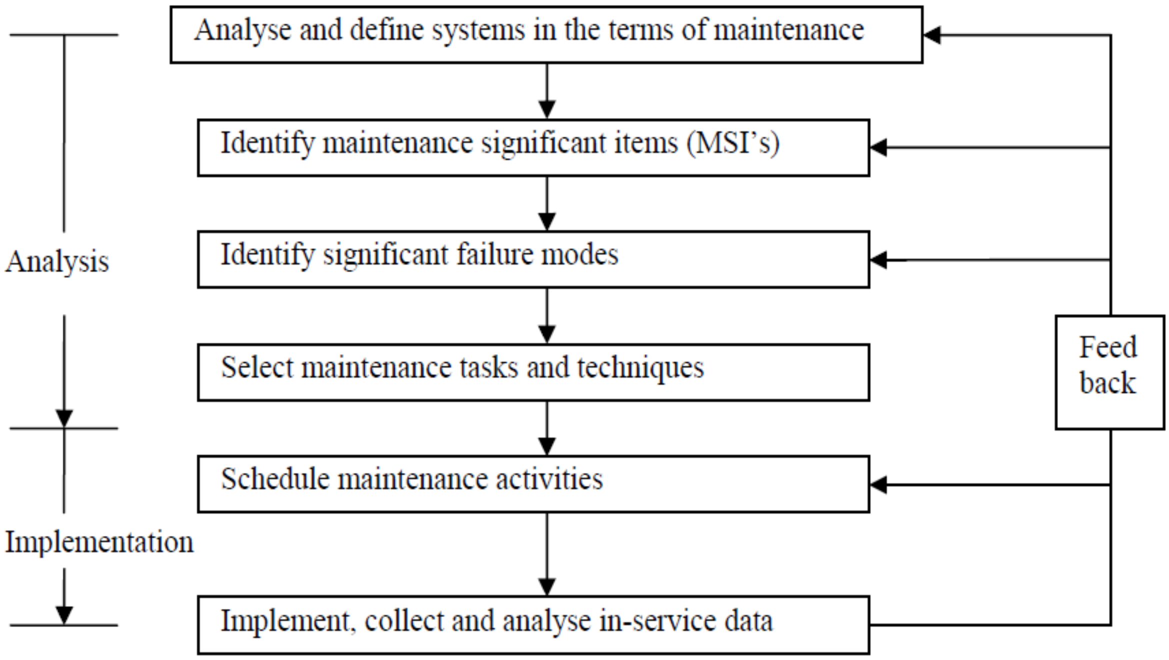

Figure 1. Basic structure of the RCM

Corrective maintenance

Corrective maintenance: Corrective maintenance can be defined as: The act of restoring a failed device to its previously operational state. This type of maintenance cannot be scheduled and therefore is usually time consuming for the system and can be very costly. The amount of corrective maintenance required is highly dependent on reliability, as reliability determines the number of failures

Preventive maintenance

Preventive maintenance is used to prevent a malfunction from occurring. Depending on the type of system, this type of service is usually performed when the system is not operational or in use. This type of maintenance requires planning and will therefore be more economical and less time consuming in the system.

Condition monitoring

Condition monitoring is used in process monitoring to detect significant changes in the process that indicate an ongoing malfunction. CBM is one of the best preventive maintenance strategies in the automotive industry and has a wide range of applications. Using condition monitoring allows you to plan maintenance or take other measures to prevent indirect damage and prevent its consequences.

Resistance spot welding systems

In the automotive industry, welding seams are used to weld body parts. In RSWS, electrical and mechanical parts can be clearly distinguished. The mechanical part of the RSWS can vary widely depending on the design and welding the machine is doing. According to this feature, dozens of different types of RSWS are used in industry. The mechanical part of the machine consists of the machine frame (on which the lower and upper consoles are fixed), the drive force system (for closing the electrodes) and the water cooling system (for the live parts of the machine). The drive force system can also be pneumatic (air cylinder), hydraulic and electromechanical (servo motor), or a hybrid form, a combination of the above two mechanisms. Among them, the pneumatic system is mainly used due to its simple structure. The driving force system of the welding machine when examining this paper is pneumatic driven. The pneumatic drive system consists of a three-chamber cylinder with two pistons, a filtration system and a lubrication system. The cooling system (let's call it hydraulic) PSW is designed to remove heat from the live parts of the machine. It consists of a pump, water pipes, hoses, valves, hydraulic switches and water filters. The electrical part of the PSW machine does not differ in its structure from the mechanical one. The electrical part is very similar to other spot welding machines [15]. It mainly consists of 4 parts: transformer, rectifier with capacitor banks, inverter and welding controller. Electrodes and electrode holders also belong to the electrical part of the machine, but they are replaceable parts and have a much shorter useful life, so they will not be considered in this study. The PSW machine and its hierarchical structure are presented in Figures 2 and 3.

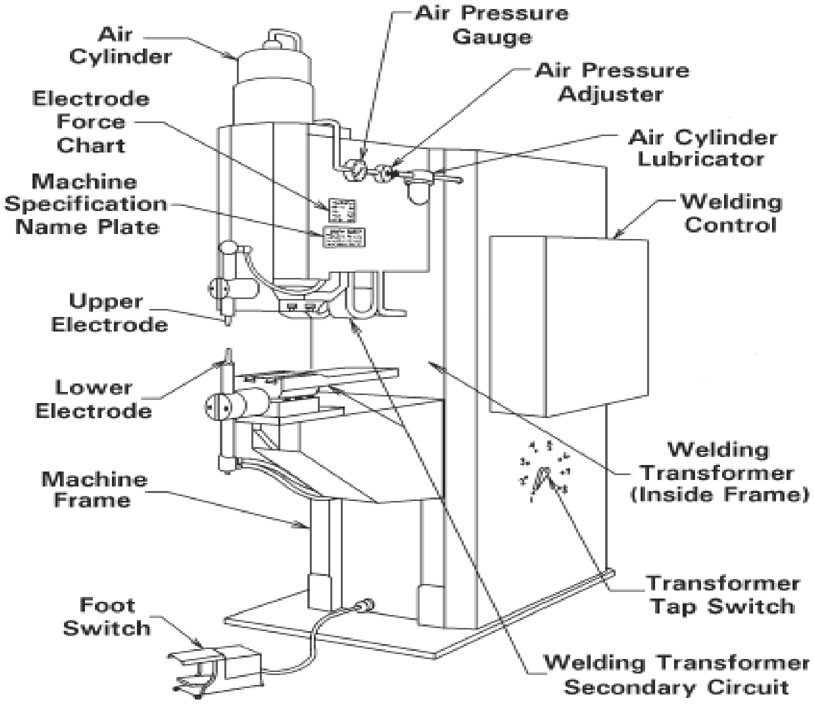

Figure.-2: Resistance welding machine.

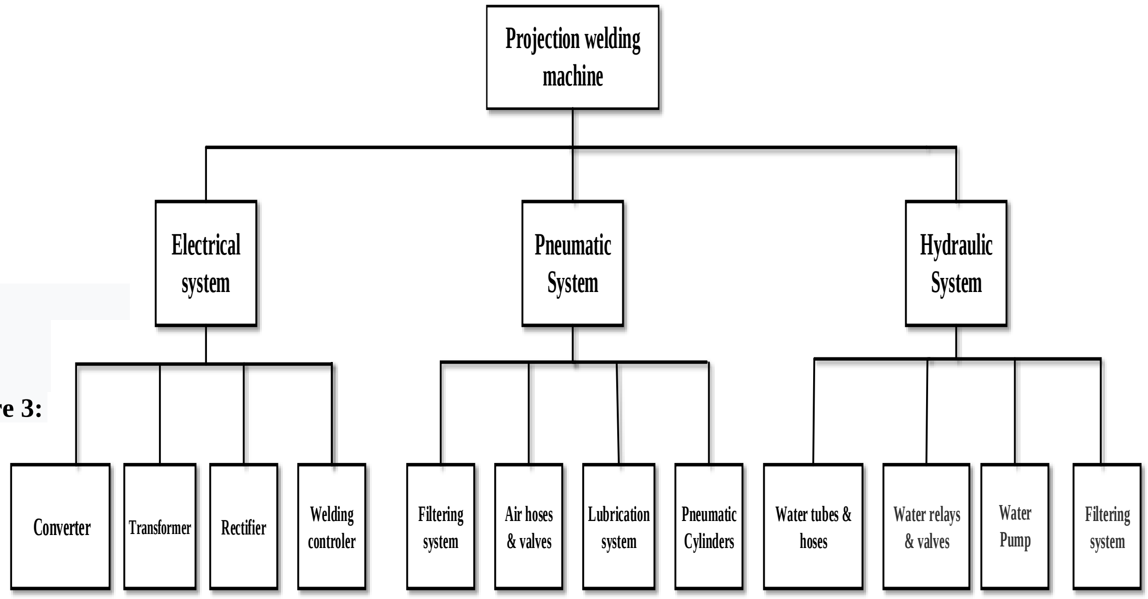

Figure 3: **Hierarchical structure of the PSW machine**

Butt welding problems in the automotive industry

The problem of quality control of the welded products is extremely costly. The process of identifying and eliminating non-convertible products significantly affects the cost of production. However, it is economically feasible to reduce the likelihood of defects by increasing the reliable function of equipment operation and personnel maintenance.

The main objective of quality control in the welding industry is to predict product nonconformity by applying a welding inspection procedure that is clearly described in the international standards ISO 16949 [16]. These test procedures are largely based on statistical information about equipment or process failure. In industries with mass serial production, the problem of quality assurance is quite successfully solved on the basis of methods of mathematical statistics. The development and integration of such methods / procedures in the assembly and welding industry is considered extremely challenging for a number of reasons. As practice has shown, the problem of ensuring the quality of welding and welded joints can be solved only with factors affecting the reliability of the system. The main problem in the implementation of these procedures is that the reliable operation of the welding machine and the quality of welded joints depend on many factors. The main ones are: the welding process, welding materials, welding and auxiliary equipment, disruption of the rhythm of work, qualifications of engineering and technical workers, defectoscopy, organization of work, welding conditions, seasonality

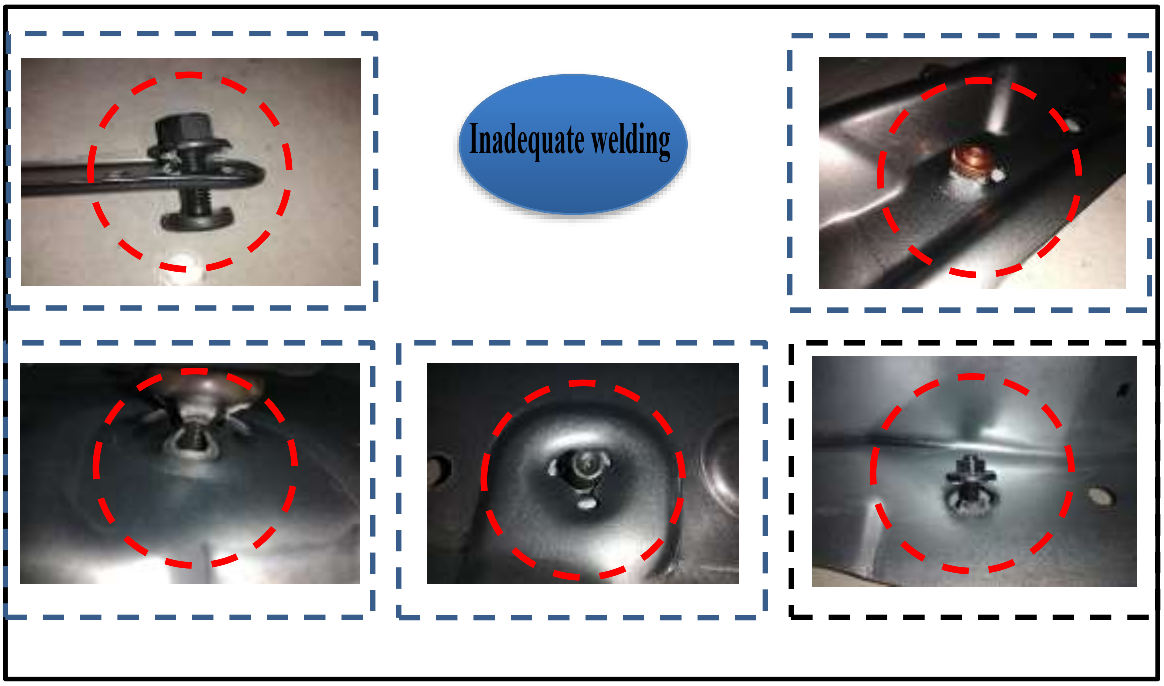

Figure 4: Defects in welded joints

Thus, in order to ensure reliable system operation and the quality of welded joints in the automotive industry, it is necessary to solve a number of sequential and interrelated problems. The photographs show defects in projection welding. This is the main problem that many car companies face. Car accidents due to inadequate welding occur all over the world. To improve the quality of the Product, it is necessary to improve the Reliability of the Equipment.

Proposed Preventive Maintenance Policy for PSW Machine

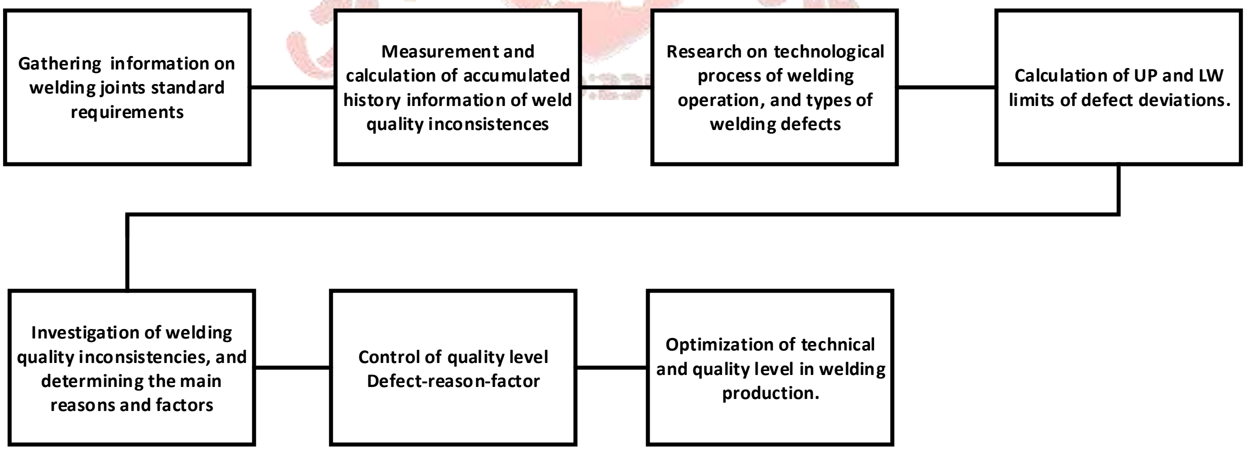

Figure 5: PSW Preventive Maintenance Strategy

The presented quality control methodology is based on the collection of historical data on nonconformities in welding operations. Various methods are used to assess the quality level of a weld in the automotive industry. Analysis of the quality of welded joints is described in [17]. One of these is Statistical Process Control (SPC). SPC is a statistical control technique that uses statistical techniques to control a process. The SPC app includes three main activities

- Understanding the process
- Eliminate changes in the process, so the process is stabilized.

 Monitoring the process using control charts.

Identifying the factors affecting the technical condition of the welding machine is an important part of ensuring the quality of the weld. Welding equipment is exposed to various harmful effects of various factors during operation. Eliminating the harmful influence of factors can greatly improve the reliability of the machine and improve the quality of the product. These factors are discussed in the next section.

Optimal service policy taking into account risks

The risk-based approach is based on an assessment of the risk caused by the failure of systems / components of a machine. In the first part, the risk of failure is assessed using a risk assessment methodology. The cumulative risk of failure and the cost of maintenance are then estimated. Finally, an optimal maintenance policy and maintenance planning with the main goal is to achieve complete risk reduction and cost savings. This approach is useful for short-term maintenance planning and resource allocation [20]. Machine components and subsystems are reviewed and categorized in terms of the importance and priority of maintenance activities. This should also include the priority of purchasing spare parts. Service policy is achieved at the level of service quantification at the component level. This approach can be further improved by calculating the replacement cost.

Risk-based analysis is a technique used to identify possible events that may occur, assess the likelihood of their occurrence and assess the possible consequences. As a result, the risk can be assessed qualitatively or quantitatively for a specific failure scenario.

Risk = Probability of Failures x Consequences of Failures

There are many different approaches in quantitative risk analysis to assess the likelihood of failure and the associated consequences. Fault tree (FT) and event tree (ET) analyzes have been widely used in accident modeling to assess the likelihood of cause and effect.

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CONCLUSIONS

Factors Affecting PSW Machine Reliability

Operational experience shows that the reliability of the PSW and its components depends on various operational factors. Operating factors include those that appear outside the design and manufacturing stage [18]. Depending on the PSW type, the classification of operating factors affecting reliability may vary. With the support of maintenance and quality control engineers, a classification of factors and their failures was identified, developed and demonstrated in Fig. 1-6. With regard to welding equipment in this study, operating factors can be divided into two categories: objective (mechanical and environmental factors) and subjective or human-related (low level of labor organization and low qualification of personnel). Mechanical impact - due to the main reciprocating movement of the movable clamp of the welding machine, strong vibration occurs, which can significantly reduce the reliability of individual elements and the entire machine. Under the influence of vibrations, numerous mechanical damages are caused to structural elements and weaken their electrical connections. The maintenance personnel of enterprises must monitor the vibration parameters and eliminate its harmful effect on the welding equipment.

Human-related - According to the literature, about 30% of failures of various technical systems are directly or indirectly related to humans [19]. This is mainly due to inadequate skills and experience of workers and maintenance personnel. Implementing techniques such as total quality management (TQM) just in time (JIT) and continuous improvement in kaizen can help improve employee skills, strengthen process discipline, and standardize welding-related manufacturing processes.

Environment - Welding equipment is mainly operated indoors; therefore, the influence of environmental factors on this should be limited. However, in many cases, in semi-open rooms, the equipment is exposed to climatic and atmospheric phenomena. Polluted air, humidity, as well as high and low ambient temperatures have a significant impact on the level of reliability of elements and all equipment as a whole [20]. In the southern part of Uzbekistan, where the equipment is operated, the climatic conditions are sharply harsh and harsh with large fluctuations in amplitude in the temperature range from -20 to + 45 ° C.

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