Shaft Failure Sea Water Pumps At the Steam Power Plant Units

Djoko Setyo Widodo, Desiran Sembiring, Bintang Adjiantoro, AB Saman Bin ABD Kader

Abstract*: *The water pump used to suck and drain seawater to the heat exchanger unit at a Steam Power Plant (PLTU), is damaged. To find out the causal factors of this damaging phenomenon, the fractured shaft is tested which includes visual observation, fractography testing, metallography, hardness testing and chemical composition analysis on a fractured shaft. By knowing the type and cause of damage to the water pump shaft, steps of prevention or prevention can be formulated so that the same damage can be avoided. From the test results, it was found that the average carbon content was lower than the AISI 316 standard. While the average hardness was lower than the standard hardness. The damage that occurs to the CWP water pump shaft is basically caused by fatigue fracture due to excessive workload in the form of dynamic loading.

Keywords: shaft, fracture, testing, corrosion, material fatigue

I. INTRODUCTION

The water pump is a device used to suck and drain seawater into a heat exchanger unit in a steam power plant (PLTU). In March 2005, there was damage to the seawater pump engine for cooling needs of a heat exchanger unit owned by a Steam Power Plant (PLTU) company in Jakarta. The pump is used to suck seawater and push it into the heat exchanger unit until it reaches a pressure of 1 bar with a flow rate of 600 tons/minute. The pump used to fill the heat exchanger unit at the PLTU is a type of centrifugal pump.

It is known that the damage to the pump is precisely on the lower shaft (lower shaft CWP 6). The shaft is one of the important parts of each engine, as well as the water pump the role of the shaft is very important to continue the rotation of the motor or drive to the impeller. From the data obtained, it is known that the pump shaft has been used for 8 years. The shaft is made of 316 types of stainless steel material, including in the austenitic stainless steel group.

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The failure of this seawater pump component must be found so that the same damage does not happen again. Component failure can occur during design, manufacture, storage, use or transportation. Failure due to incorrect design such as errors in material selection, determination of load, work process, determination of highly corrosive operating environmental conditions. In addition, corrosion damage can also occur. Therefore, it needs to be analyzed from a number of these factors, which are the causes of component failure in the case of this seawater pump.

The purpose of this study is to determine the type and factor that causes damage to the water pump shaft. By knowing the type and causes of damage, then further instructions and suggestions can be made to take steps to prevent or prevent according to the type and cause of damage. The ultimate goal is to avoid the same damage and not repeat itself.

II. METHODOLOGY

This research was carried out by previously conducting a literature review, then continued with testing the pump shaft material in the laboratory. The literature review approach is directed at the analysis of the theories related to the problems faced, then linked to the fact of the damage that occurred on the shaft. While laboratory tests are directed at studying phenomena that occur in damaged shaft material.

In this study, various tests and analyses were carried out, including fractography testing, metallographic testing, dimensional measurement, mechanical or hardness testing, and chemical composition analysis of seawater pump shaft material. The research procedure used in this study can be seen in Figure 1.

A. Visual Checking

The test in this study begins with a visual inspection, which is a check directly from the shaft of the centrifugal water pump that has been damaged. Parts are examined mainly on the surface of the fracture. Visual inspection includes looking for initial cracks or fractures, taking photographs from various directions, marking important positions as identifying damage information.

B. Fractographic Examination

The fractographic examination is used to determine material defects such as porosity, *impurities*, corrosion, crack growth rates. Fractography examination also aims to determine the location of the start of damage or initial cracks. This check is also to find out the type of damage, whether it is due to tensile, press, shear, or other stresses.

Fractography testing is carried out using a stereo microscope which is useful for knowing the surface fracture characteristics of a fractured shaft. The fractographic examination can be carried out on two observation scales, namely macroscopic and microscopic. Macro photography examination using an optical microscope. Before testing the specimens the test object is cleaned from the impurities through immersion into the ethanol beaker glass which is placed in an ultrasonic cleaner, then dried with a dryer.

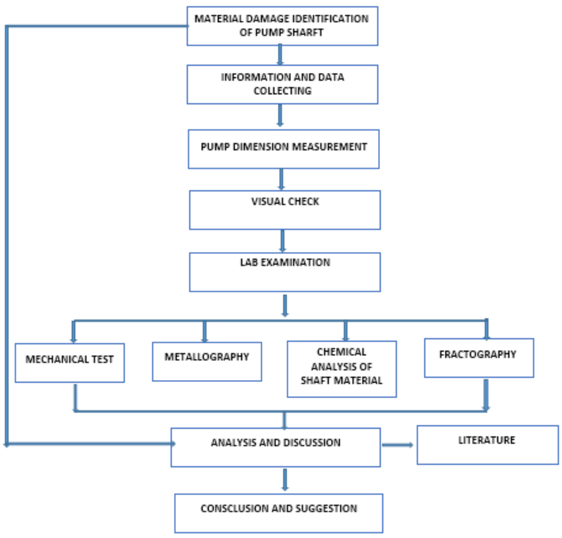

Figure 1. Research Flow Chart

C. Metallographic Examination

Metallographic testing aims to observe the microstructure of fracture porous parts, then compared to material that has not failed. By performing a metallographic examination, it can be seen whether there are microstructure changes that occur in the material that has been damaged.

D. Tensile Testing

Tensile strength testing is carried out on shaft material with the shape or size of the test sample using the ASTM-A 370 standard as shown in Figure 2. The dimensions of the tensile test specimen are 50 mm long and 12.5 mm in diameter.

E. Test of Hardness

Testing of shaft material hardness is carried out in the Construction Test Laboratory (LUK) BPPT using Brinell hardness method with ASTM-A 370 standard. This test is carried out to determine the hardness of shaft material in the area around the fracture and on other parts of the shaft which are not affected by fracture. As a penetrator, hardened steel balls are used. The steel ball is pressed into the specimen with a certain load and time. The amount of load imposed on the penetrator depends on the diameter of the steel ball and the type of metal of the test object. The principle of testing is to calculate the ratio of the load used to the area of the press area.

F. Chemical Composition Analysis

Chemical composition analysis carried out on the shaft material of the seawater pump was carried out at the Metallurgical Research Center-LIPI Chemical Analysis Laboratory. Tests are carried out using a spectrometer. The goal is to find out the type of chemical content and the prescription of the damaged water pump shaft material. This test is to find out the main elements of the material, such as the content of C, Mn, P, S, Si, Cr, or Ni. The results of testing the chemical composition are matched with standard data on material specifications. In this way, you can find out the type of material used by the shaft of the water pump.

III. DISCUSSION

The pump is one of the important units in a hydraulic system, which functions to drive fluid flow and channel it to all piping and process units or a pump that can convert mechanical or motor power into hydraulic or fluid power. The pump serves to move fluid from a reservoir to the processing unit. According to Dietzel, the shape of pump impellers is divided into centrifugal pumps, helical pumps, diagonal pumps and propeller pumps (Dietzel, 1992). Some types of pumps used in a power plant center are boiler fill pumps, condensate pumps, water circulation pumps, and so on.

Component damage or failure can be defined as a change in the component or structure of a machine or pre-manufactured equipment, in such a way that the component is no longer able to carry out its actual function satisfactorily (Alexander, 2000). Basically, damage experienced by a component can occur in two levels. First, system failure, that is, if the mechanism of the system does not function as a whole. Second is a component failure that is, if one or more of a component is damaged, causing the function of a system to be disrupted. Component failure can occur during use, it can also occur during manufacture, storage or transportation. Failure can also occur due to design errors, such as errors in material selection, load determination, work processes, determination of highly corrosive operating environmental conditions.

In the case of this PLTU pump, the damage to the pump is classified as component damage, namely the bottom shaft component. The shaft of the pump that has fracture during the operation experiences dynamic loading, so there is a possibility that the shaft is fractured due to fatigue. When objects experience loading with repetitive loads or dynamic loads, damage can occur at very low load levels compared to resistance to static conditions (Dieter, 1992). Although dynamic loading occurs in elastic areas but has been able to cause plastic deformation locally on weak metal parts, or called microplastic.

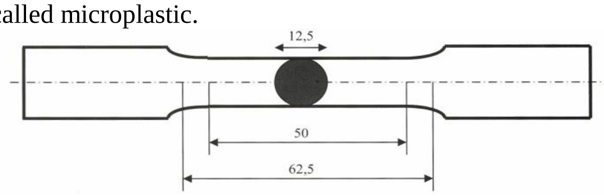

Figure 2. Shape and Size of Tensile Sample

A part from that, the fracture water pump shaft works in a seawater environment that has been used for several years, so that the cause of damage due to corrosion can occur. Corrosion is a decrease in the quality (degradation) of metal or non-metallic materials due to chemical or electrochemical interactions with the environment. Forms of corrosion attacks that occur in steel or metal material are evenly distributed, pitting corrosion, crevice corrosion, galvanizing, stress, selectivity, inter grain, erosion and fatigue corrosion (fatigue corrosion) (Widiarto, 1999).

A. Visual Observation and Dimension Measurement of CWP Shaft

As planned, the first analysis carried out on the damaged component is visual observation. At this initial stage, the dimensions of the CWP shaft are also measured. Dimension measurements are also made for upper shaft components that do not experience damage as a comparison. The results of CWP shaft dimension measurements are shown in Table 1 while the results of visual observations are shown in Figure 3.

Based on the results of measurement of shaft alignment performed, it turns out there is a curvature in both the upper and lower shaft. The occurrence of curvature on the water pump shaft is initially from the bearing (bearing). The bearing made of the Belzoni layer causes unstable shaft rotation or also called rotating bending and the torque. As a result of the unstable shaft rotation, tensile and compressive stresses arise at certain points along the lower shaft and upper shaft. The tensile stress in the horizontal direction results in a moment bending which causes a curve to the shaft even though it is not physically visible. After the measurement is made, it turns out that the upper shaft curvature is 0.4 - 0.6 mm and the bottom shaft is 9 mm.

Table 1. Result Data of Shaft Condition Measurement

Shaft Condition CWP	Up Shaft	Down Shaft
Length	2800 mm	3701 mm
Large	0.4-0.6 mm	9 mm
Curve Toward the Shaft Surface	165 mm	165 mm
Weight	450kg	620 kg

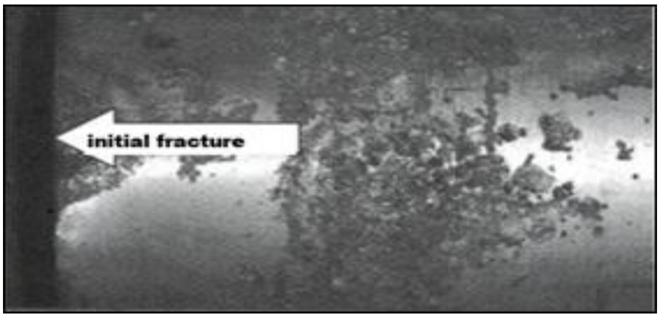

Figure 3. Center of Initial Fracture on Shaft outside Section

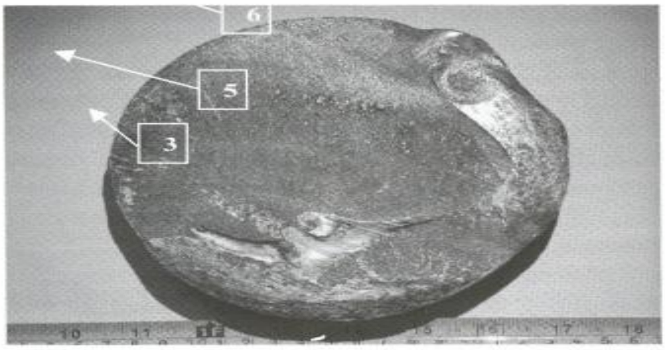

Figure 4. Position of Observation of Macro Structures

Visual inspection includes taking pictures directly on the bottom shaft that has a fracture. The shooting location is in the cross-section of the fracture and the outer area around the beginning of the fracture. In Figure 3 we can see the damage experienced by the shaft. In the outer area of the shaft, there is pitting corrosion near the beginning of the fracture. Damage is not very clearly seen in the cross-section of the fracture because it is slightly damaged due to the impact and corrosion of the surface, but the beginning of the fracture and the final fracture is still apparent. The cross-section of the shaft fracture will be clarified in fractographic testing. Figure 4 shows a cross-section of the fractured shaft.

B. Fractography Testing

In Figure 5, there is a corrosion attack on the outer cross-section of the shaft which is far from the beginning of the fracture. This shows that the pump shaft has been attacked by a lot of corrosion. From the observations in Figure 5, it also appears that the most corrosion occurs in the initial area of the fracture.

The initial area of the crack marked with an arrow indicates a centered marking that has spread and has spread into the center of the shaft. The sign is not clear because the initial crack has been damaged due to being hit and scratched during the release process. This area is located on the shaft surface which is affected by pitting corrosion which has spread into the shaft causing a high-stress concentration.

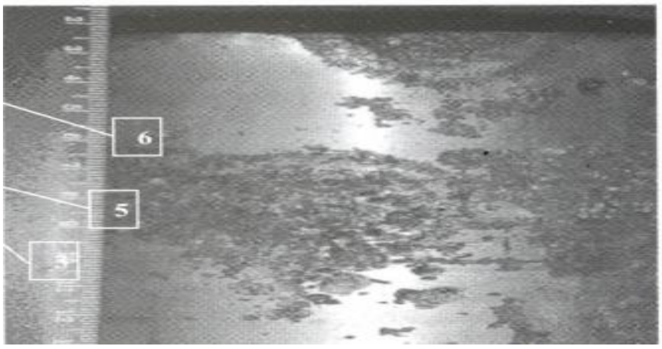

Figure 5. Position of Micro Structural Sampling at the Beginning of the Shaft Cross Section

The occurrence of pitting corrosion attacks is estimated to be caused by inundated seawater at the start of the installation of the pump. During installation, the pump is not directly in use and while waiting for the operating, the shaft is flooded by the seawater. Another possible cause is the presence of chloride (CI) in seawater.

The area of crack propagation is indicated by a different line pattern, namely rough and smooth lines. The area is divided into 2 parts, namely the rough fatigue area is located at the beginning of the crack and the fine fatigue area is located at the end of the crack. It can be seen in Figure 6 that the contour of the fracture surface shows plastic deformation. Plastic deformation due to ductile fracture is also seen in Figure 7.

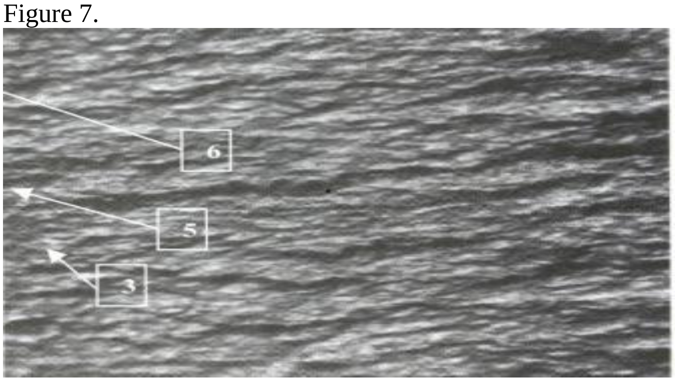

Figure 7. Macro Structure of Samples A. 12x Magnification.

The final fracture area occurs at the end of the stress cycle, ie when the remaining cross-section of the shaft is no longer able to hold the shaft load. Fracture fatigue can be identified from the surface of the fracture, ie there is a smooth area due to the effect of friction when the crack spreads due to the loading cycle. Another characteristic is the presence of the remaining rough surface as the final fracture area due to overload. This final fracture can be brittle, resilient, or a combination of both.

Analysis of loading conditions associated with the shape of the fracture surface that occurs is done by looking at the reference section due to fatigue fractures as shown in Figure 8. In Figure 8, a sketch of several high-stress conditions or (low nominal stress) can be seen for some loading.

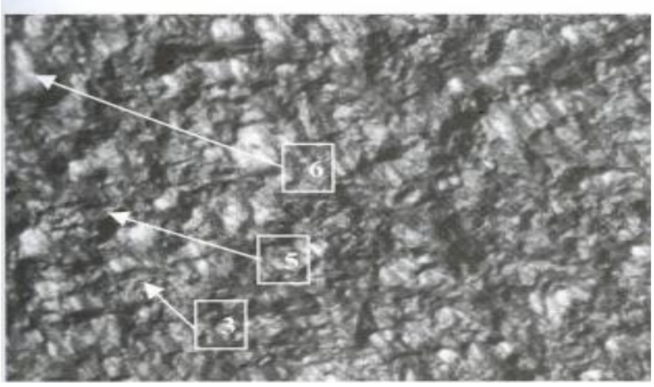

Figure 6. Macro Structure in Samples B. Magnification of l2x

The result of the comparison between Figure 3 to Figure 8 with Figure 9 as a reference, which is similar to the damage to the lower shaft CWP is damage caused by dynamic loading. Dynamic loading here is a combination of rotating bending and torque with a nominal low-stress level. This situation shows that the lower axis of the CWP in operation receives a normal load, but with the rotating bending, the shaft becomes curved. The initial factor that causes the shaft to break is the presence of fatigue and triggered also by the surface of the surface that is corroded by the well that has propagated to the center of the water pump shaft.

C. Test of Hardness

Testing of hardness is done on fracture water pump shaft material using the Hardness Brinell (HB) method. The results of the testing of hardness are indicated in Tabe12. The test takes 14 sample points on the cross-section (X_1, X_2, X_3, and X_c), the four values obtained are then averaged so that the hardness value is more accurate.

Testing the hardness of the shaft fracture section is carried out at 4 points, X_1, X_2, X_3, and X_c. This is intended to find a more accurate hardness value from the cross-section of the shaft. The hardness of the cross-section of the shaft pieces is almost even, after averaging from the 4 test points, the shaft cross-section hardness value is 127.15 BHN.

The comparison in Table 2 shows that the water pump shaft material has a relatively lower hardness value compared to the standard material hardness of AISI 316. This is probably due to the influence of non-homogeneous shaft material or chemical composition that is not in accordance with the standard. If the results of the chemical composition test are reviewed, the carbon content is lower than the carbon content of the AISI 316 standard material which will result in a lower value of material hardness.

D. Tensile Testing

Tensile testing is carried out on the shaft material three times using the UPM 1000 tensile testing machine. The test results are shown in Tabe1 3. Tensile testing was carried out 3 times at the end near the shaft fracture section, ie sample 1, until 12 and sample 3. The three tensile strength values were then taken to obtain a more accurate tensile strength value. Tensile test samples are formed according to tensile test specimens according to ASTM-A 370 standards.

Comparison between the tensile strength of the shaft pump and standard material AISI 316 is carried out in three parameters, namely tensile strength, yield strength, and elongation. The comparison can be seen in the bottom two rows in Table 3. The value of the tensile strength of the water pump shaft material (by 7.56%) of the tensile strength of AISI 316 material, but the shaft material has an increased strength (17.27%) and extension also increased (by 17%) compared to AISI 316 material. This shows that the water pump shaft material is resilient. As a result of such material properties, the tendency will occur preparing or mulching and shaft curvature.

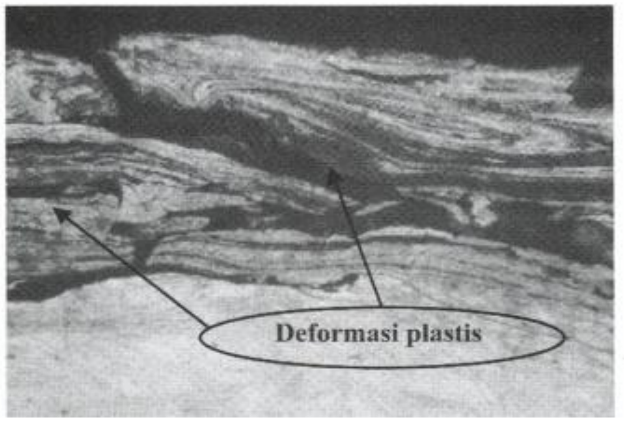

Figure 8. Plastic Deformation Contour from the Initial Cross Section. 200x Magnification Location 3.

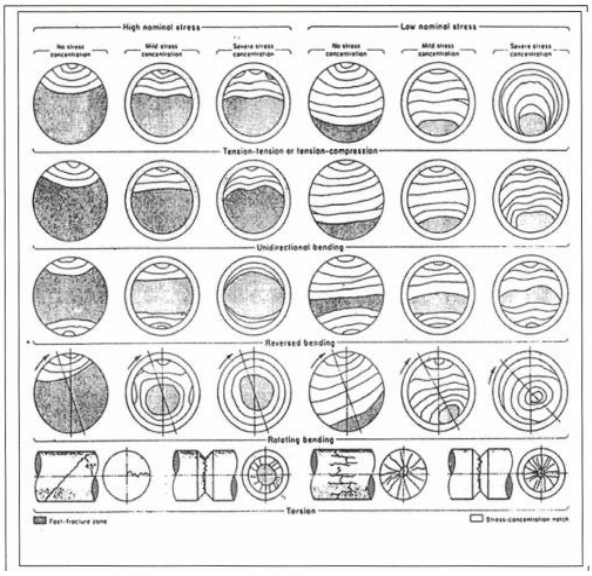

Figure 9. The difference in Forms of Fracture Surface Due to Fatigue of Various Types of Loading and Tension Levels of Source: Adnyana (2003).

E. Chemical Analysis

Chemical composition analysis was carried out on shaft material using a Spectrometer. This chemical composition testing is carried out in three areas on the water pump shaft. Data retrieval in these three places aims to make the test results more accurate. The test results are shown in Table 4. Testing of chemical composition is carried out on the shaft material used. Two of the three chemical composition test results show that the water pump shaft material is close to the AISI 316 standard material specification.

Table 2. Brinell Hardness Test Results Data

Testing Position	X_1	X_2	X_3	X_C	Average
Water Pump Shaft	128,2	125,6	129,6	125,2	**127,15**
Standard of AISI 316 (annealed condition)					**150**

Table 3. Test Results Data Drag

Tensile Test Samples	Mechanical Properties		
	Tensile Strength (Ωt), N/mm^2	Yield Strength (Ωt), N/mm^2	Lengthening (e),%
Sample 1	533.81	242.64	65
Sample 2	549.09	282.62	65
Sample 3	541.89	323.50	65
Value Average	541.89	282.92	64.33
Standard of AISI 316 (annealed condition)	**585.9**	**241.25**	**55**

Table 4. Chemical Composition Data of CWP Shaft I and Standard Composition

Chemical Composition	Shaft Measurement (Weight %)	Standard 316 (Weight %)	Standard 316 L (Weight %)	Standard 304 L (Weight %)
C	0.038	0.08	0.03	0.030
Si	0.41	1.00	1.00	1.00
S	0.004	0.030	0.030	0.030
P	0.03	0.045	0.45	0.045
Mn	1.27	2.00	2.00	2.00
Ni	8.49	10.00-14.	10.0-14.0	8.00-12.0
Cr	18.92	00	16.0-18.0	0
Mo	0.093	16.0-18.0	2.0-3.0	18.0-20.0
V	0.132	2.0-3.0	0	0
Cu	0.16	0	0	0
W	<0.0001	0	0	0
Ti	0.005	0	0	0
Sn	0.01	0	0	0
Al	0.012	0	0	0
Nb	0.011	0	0	0
Zr	0.006	0	0	0
Zn	0.015	0	0	0
Fe	70.4	61.845	61.895	0
				64.9

IV. CONCLUSIONS

The damage that occurs to the CWP water pump shaft is basically caused by fatigue fractures. This type of damage occurs due to workload caused by dynamic loading in the form of torque and rotating bending with a level of loading that is still within the allowable threshold (nominal low stress).

Fatigue damage that occurs on the shaft can be caused by carbon content in the water pump shaft material (0.06% C) which is lower than the standard AISI 316 (0.08% C). Damage can also be caused by the hardness of the lower water pump shaft material compared to the standard value of stainless steel 316. Another factor is the finding of ductile properties and the tendency to occur in the shaft or curve.

The last factor is pitting corrosion which attacks the shaft surface which propagates to the porous center resulting in stress concentration. Damage to the water pump shaft can be caused by one or a combination of these factors. Similar research needs to be developed by selecting other shaft material with higher material specifications (especially resin resistance, tensile strength and hardness) or the same type of material but with specifications that meet the standards.

Analysis of the damage to the pump shaft of seawater can be added with a vibration analysis so that the factors causing damage to the shaft will be more quickly known. Vibration analysis will also provide input for vibration monitoring during operation. Another thing that also needs to be further deepened is the knowledge of the composition of seawater flowing through the pump. This is so that the contents can be known, especially those that have the potential for corrosion. The hope is that in the next development efforts can be made to prevent corrosion, such as the use of inhibitors, coating anti-rust materials, or the like.

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