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Žegarac, Nikola P.

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IMPROVING TECHNICAL MAINTENANCE OF SYSTEMS OF MINI HYDROPOWER PLANTS - ANALYSIS OF CAUSES OF MALFUNCTIONS, FAULTS, FAILURES AND SYSTEM FAILURES

Nikola P. Žegarac
Serbian Academy of Inventors and Scientists, Belgrade,
Republic of Serbia,
e-mail: zegaracnikola@vektor.net,
ORCID iD: http://orcid.org/0000-0002-1766-8184

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Summary:

The paper presents many years of experience related to the activities of technical maintenance of mechanical and electrical plants. It shows the analysis of the cause of many malfunctions, faults, failures and system failures that occur in mini hydropower plants. Systems of mini hydropower plants are discussed in terms of improving the technical maintenance by functional units: turbine regulator with turbine, mechanical assemblies (multiplier and flywheel), flexible couplings that connect plant assemblies, electrical circuits, lubrication systems, automation and high-voltage installations. Below is a brief overview of the application possibilities of technical diagnostics i.e. of a monitoring system in mini hydropower plants.

Key words: technical maintenance, mini hydropower plants, faults, malfunctions, system failures, bearings, flexible couplings, mechanical assemblies, electrical circuits.

Introduction

The paper presents many years of experience in the technical maintenance of rotating mechanical and electrical installations. The causes of many malfunctions, faults, operation failures and system failures are assessed from the scientific point of view while contributing to the improvement of technical maintenance systems used for mini hydropower plants, which are of particular importance for the production of electric power. Mini hydropower plants are included in the power grid system with other power systems: thermal and hydropower plants. The maintenance of machinery, equipment and complex technical systems in terms of necessary investments during their service life is directly connected with the ways of defining and achieving the desired efficiency (reliability, certainty and benefits for maintenance) in the design phase as well as during operation. A well-chosen concept of maintenance with a proper organization, programming and realization of certain maintenance activities as well as with a good level of personnel training and provided maintenance has a significant impact on increasing the production of electric power, reduction of maintenance costs, fewer faults, failures in operation and system failures. The period of exploitation of systems is longer. Maintenance of a technical system during its operational cycle unites a series of accompanying activities, starting from the idea and the definition of the concept of assessment of its cost-effectiveness, implementation, and operation, to the end of the plant exploitation.

An indispensable part of the plant operation cycle represents revitalization, reconstruction and modernization of technical systems or the process life cycle extension with an additional technical and technological, economic and environmental acceptability. Due to its structure, this process is extremely complex and is often compared with the implementation of new technical installations. The process of planning and implementing the revitalization and exploitation of the plant itself within the framework of the considered system is implemented with the aim of achieving a high level of operational safety, including the definition and detection of possible sources of uncertainty. The measures for removing and mitigating their effects must be defined and the criterion mostly used is the economic criterion (Milovanović, 2014).

The processes of technical maintenance (intermediate overhaul, general revision and general system overhaul) are directly connected to the extension of the service life of mechanical and electrical installations. This systematic and comprehensive process applied in mini hydropower plants is an inevitable and logical process in the plant operational life.

Mini hydropower plants systems

The benefits of constructing mini hydropower plants (MHPs), (in Serbian: MHE - mini hidro elektrane) in comparison to the construction of other energy sources are numerous:

- In comparison to large hydropower plants (LHPs), there is neither flooding of large areas (in order to provide space for water accumulation) nor disruptions of local ecological systems,
- they can provide land irrigation and water supply for surrounding communities, construction of ponds and flood protection,
- they reduce investments for the electrification of remote settlements from the general power grid and the electrification of these rural settlements contributes to their development,
- they have low-cost exploitation,
- their operational life is very long, practically unlimited; their average life is 30 years, although there are MHPs already working for 80 years.

  In the literature there is different information on how to define mini hydropower plants. There are virtually no two countries with an identical system division. The basic parameters to be used in the classification of MHPs are (Žegarac, 2016):

Installed power of hydro units:

- Type of aggregate in relation to the turbine, and the method of operation,
- the number of revolutions per minute (rpm),
- Operation in relation to the overall energy system,
- Installed head, etc.

Depending on their power, plants can be divided into micro-power plants up to 100 KW, mini power plants up to 1 MW and small or medium-sized power plants up to 10 MW. Also, in accordance with the available head and power, they can be divided as outlined in Table 1.

Table 1 – Types of mini - hydro plants
Таблица 1 – Виды мини-гидроэлектростанций
Табела 1 – Врсте мини хидроелектрана

Type HPPs	Power (KW)	Head (m) small	Head (m) middle	Head (m) large
Micro HPPs	to 50	below 15	15-50	over 50
Mini HPPs	50-500	below 20	20-100	over 100
Small HPPs	500-5000	below 25		over 130
Type HPPs	Power (KW)	Head (m) small	Head (m) middle	Head (m) large

The division of MHPs depending on available head is accepted in most countries that define their equipment in accordance with that criterion. So, for example, a number of manufacturers of electro-mechanical equipment in the United States produce standardized hydro generators including a turbine, a synchronous generator with an automatic control system, inlet valves, the control panel for the maximum head of 15 m and a power of 10 to 5000 KW. MHPs are further divided:

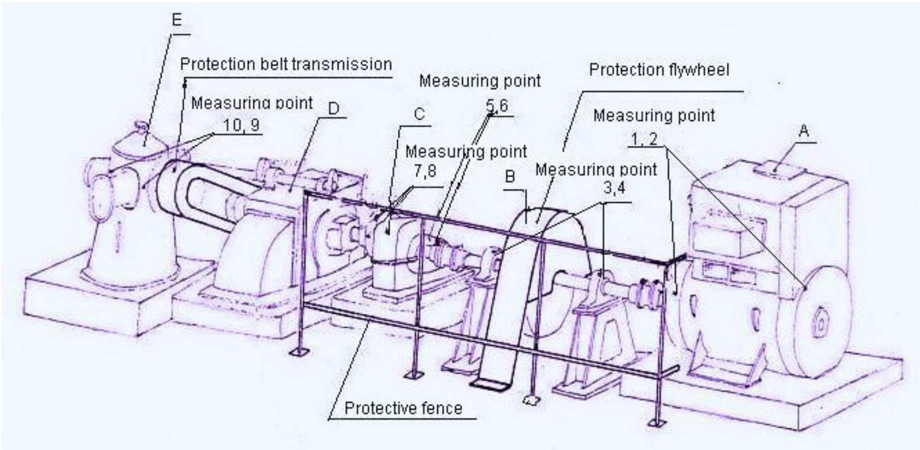
a) Depending on the procedure:
- Flow with a side intake from the main river,
- with a reservoir dam, with daily, weekly, annual or perennial smoothing

b) Depending on the flow regulation:
- MHPs with an adjustable flow controlled at the turbine inlet (manual or automatic control)
- with a constant flow rate, either because of the actual nature of the load or due to the removal of excess energy,

c) Depending on the grid and operation mode:
- Isolated HPs-independent operation,
- Plants connected to the grid-parallel operation,
- Power plants operating under the regime of on-off ±
- Plants with one, two or more units,
- Plants that operate if necessary, depending on consumption,

d) Depending on the installed capacity of hydropower :
- Pocket hydro electric power plants to 20 KW,
- Small HPPs from 0.5 to 1 MW,
- Small hydro power plants from 1 to 3 MW
- Medium HPPs from 3 to 10 MW,
- Large HPPs over 10 MW.

At the request of purchasers, we mostly performed technical maintenance (emergency, intermediate overhaul, general revision and general overhaul of power plants) of systems of mini hydropower plants in the Electrical Industry of Montenegro (EPCG). The general scheme of such mini hydropower plants is shown in Figure 1 (Žegarac, 2016):



A - Generator, B - Flywheel with flexible couplings type Flender series ARPEX K430, C - multiplier with a Flender flexible coupling type N-EUPEX, D - turbine, E - Turbine regulator with a belt drive, 1,2 - Generator bearings, 3,4 - Flywheel bearings, 5,6 - Bearings of the output shaft of the multiplier, 7,8 - Bearings of the drive shaft of the multiplier, 9,10 - Bearings of the turbine controller

Figure 1 – Scheme of the plant and the measurement points of a mini hydropower plant
Рисунок 1 – Схема установки и точек измерения на установках мини-ГЭС
Слика 1 – Шема постројења и мерних места на постројењу мини-хидроелектране

Technical maintenance of the HP plant element: turbine with a controller

In the system of the Electrical Industry of Montenegro, mini hydroelectric power plants of different capacity were installed many years ago. At the locations of Podgor and Rijeka Crnojevića, where there is a large flow rate and a low head, 4 vertical hydro units were installed. The power of each power unit is 1.2 MW with Kaplan turbine systems. The bearings power system was realized with 3 sliding bearings. One type is plain bearing – combined radial-axial bearing (turbine bearing) while the other two bearings are radial plain bearings (Figure 2).

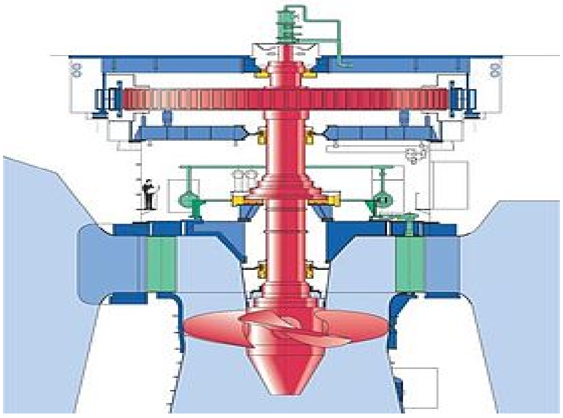


Figure 2 – Kaplan turbine
Рисунок 2 – Турбины Каплана
Слика 2 – Каплaнова турбина

Horizontal mini hydropower plants were installed at other locations. At the locations with high head, mini hydropower plants from 60 to 450 Kw were installed. These mini hydropower plants do not have a toothed gear drive for power and torque (multiplier). The hydroelectric power plant power is realized through high head. Torque is transmitted directly to the plant generator. At these sites, Pelton turbines (Figure 3) or Francis turbines (Figure 4) are installed. Flow is controlled by adjusting wicket gates (yellow on a Francis turbine).

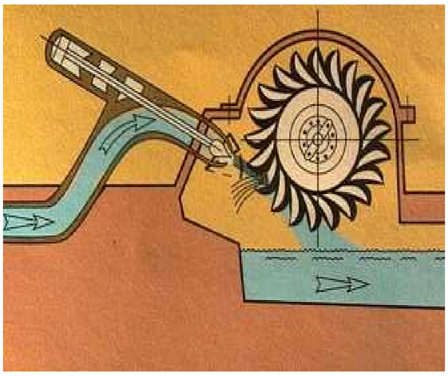


Figure 3 – Pelton turbine
Рис. 3 – Ковшовые турбины Пелтона
Слика 3 – Пелтонова турбина

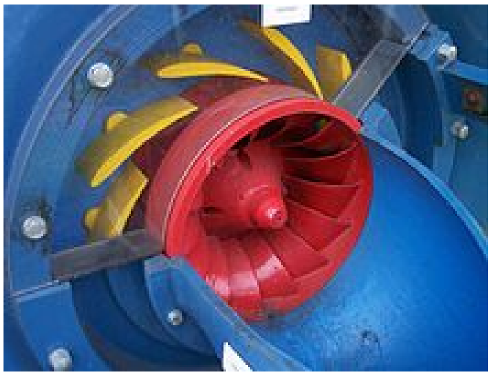
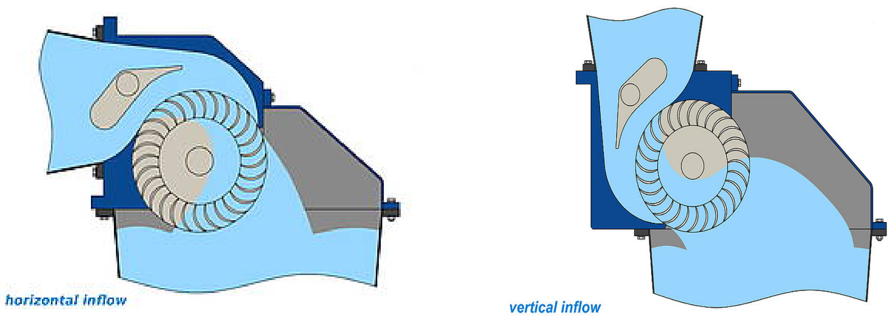


Figure 4 – Francis turbine
Рис. 4 – Турбины Френсиса
Слика 4 – Францисова турбина

At the locations with a low head of water but a higher output at mini hydropower plants, gear drives of power and torque (multipliers) are built in to increase the speed (n) of the turbine rotation from n=450 - 500 (min^{-1}) to n=1500 ((min^{-1}), (frequency of the city grid f = 50 Hz). In this way, hydroelectric power can be increased up to 600 kW. The turbine part is an Ossenberg turbine with an associated turbine controller. The flow of water into the turbine pipe can be horizontal or vertical (Figure 5a). The flow of water is horizontal in the mini hydroelectric systems of the EPCG (Figure 5a).



a) b)

Figure 5 – Ossenberg turbine
Рисунок 5 – Оссенберг турбины
Слика 5 – Ossenberg турбине

During system exploitation, there are malfunctions in the turbine controller. The adjustment of turbine controllers is performed only by authorized institutions and licensed technical staff. These tasks are regularly performed by the Turbo Institute, Ljubljana (Slovenia) and the Lola Institute, Belgrade. In the 1960s, there was a tragic accident at a location in a mini hydropower plant. There was an uncontrolled rotation speed and the flywheel was ejected from its housting, causing the death of a person standing by. The turbine control is shown in Figure 6 (Tehnička dokumentacija za elektro hidraulični regulator tipa EHR-80 za male hidroelektrane, 1968). Electromagnetic valves have a very important function of opening and closing the water flow. Some well-known manufacturers of electromagnetic valves are: DDR ORSTA Hydraulic, East Germany and Prva Petoletka, Trstenik, Serbia.

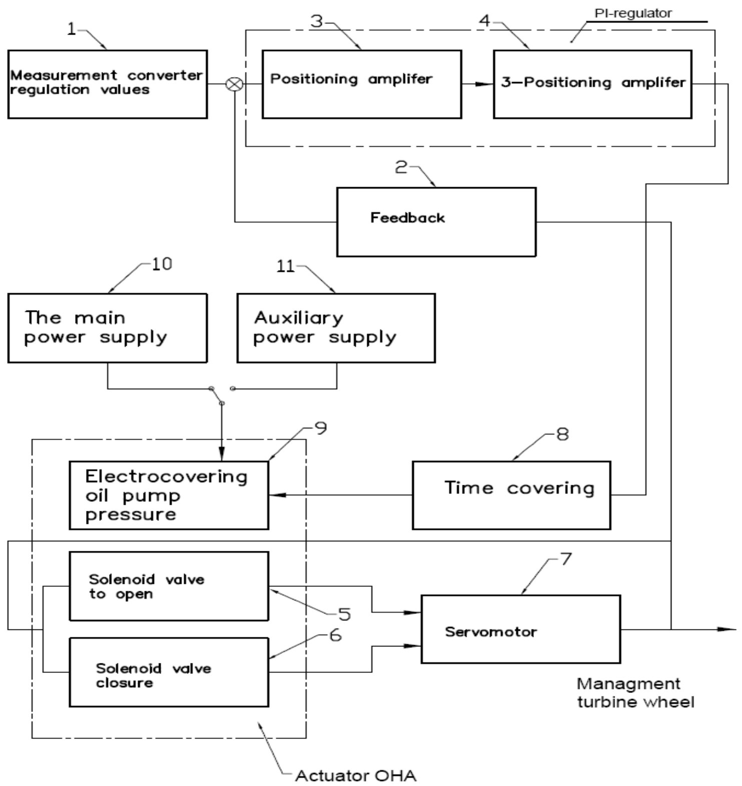


Figure 6 – Electro hydraulic controller type EHR-80 for MHPs
Рисунок 6 – Электрогидравлический регулятор ЭГР-80 для Мини ГЭС
Слика 6 – Електрохидраулични регулатор тип EHR-80 за МНЕ

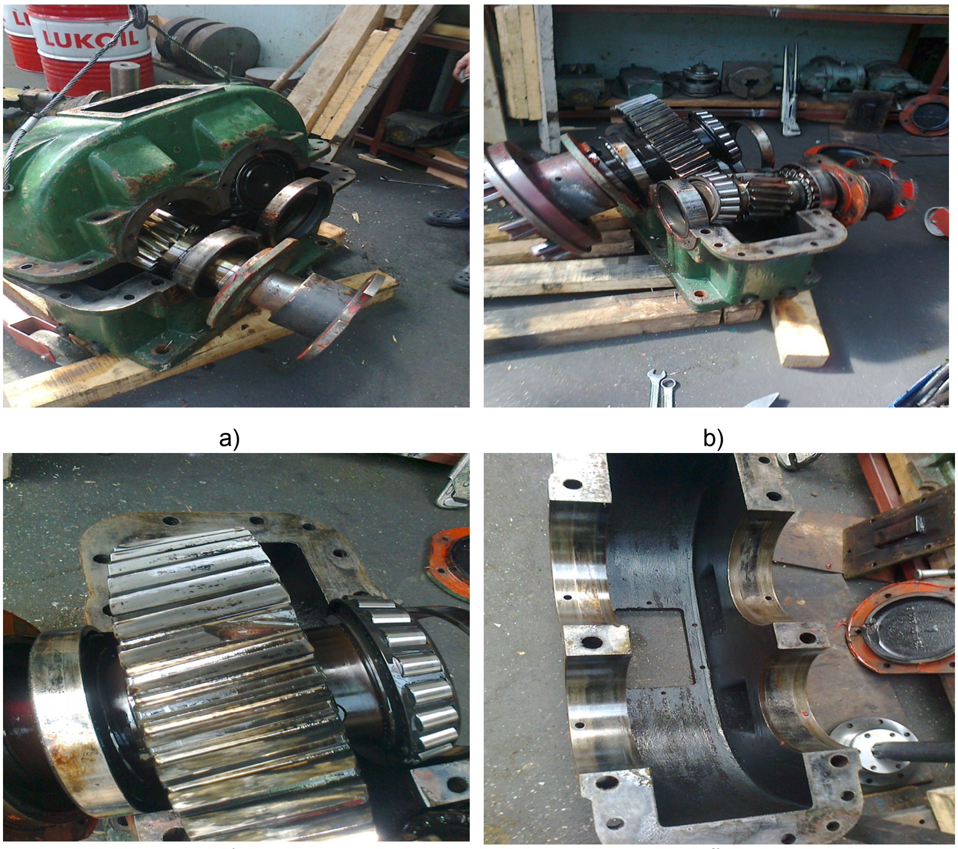
The turbine controller has a belt transmission which should be particularly taken into account during maintenance. Only original belts of the same length should be used, since there are more belts on the same pulley. Belts are in the form of tapes - flat belts. To be able to perform installation, the ends of belts are connected with special couplings. Improvisation in connecting the belts is not allowed (Tehnička dokumentacija firme Flender, 1975), (Tehnička dokumentacija za MHE, 1980).

During the operation of hydropower plants, the turbine rotors are damaged, especially at places of higher flows of water and higher hydropower. Various types of damage and pitting occur on turbine blades. Common wear includes cavitations, fatigue fractures and abrasion due to solid particles in water. Steel parts are repaired by welding. When repair is not possible, a new part is made. Specialized manufacturers are Turbo Institute, Ljubljana, Litostroj, Slovenia and Lola Institute, Belgrade.

For example, Lola Institute in Belgrade has made a very successful design and production of the generator for the MHP ″Seljašnica″ near Prijepolje (Razvoj, projektovanje i proizvodnja radnog kola Peltonove turbine, 2010). The maintenance of the bearings in the turbine system will be described in more detail in the next chapter.

Maintenance of mechanical assemblies in mini hydropower plants

Very important assemblies in the system are mini hydropower plant mechanical assemblies: gearbox and flywheel with its bearings. Multipliers used to be designed as single-gear assemblies. The transmission ratio ranges from $i = n_1 / n_2 < 1$, where n_1 =450 to 500 (min^{-1}) - speed turbine - driveshaft multipliers, n_2=1500 (min^{-1}) - speed output shaft multipliers. The gears are cylindrical with inclined teeth. The module of a gear tooth ranges from m= 6 to 8 mm. The tooth inclination angle is usually $\beta=12$ °. Drive and output shafts are in the horizontal plane of the multiplier assembly. During the regular exploitation of hydropower plants, another problem is an uncontrolled flow of groundwater. In a season when there is a large flow of water in the plant, water spills from the supply channel; in addition, there is a large influx of rain water and all that water goes underground beneath the MHP facility. Besides, another big problem is caused by branches and floating wood carried by flow to the inlet channel of hydropower plants. Since this is a karst terrain, this leads to subsidence and cracking of the concrete foundations of power plant assemblies. Multipliers are especially sensitive, since they rely on a small surface of the foundation. Their weight is over 500 kg. During operation, there are large shock loads in the transmission of energy. These phenomena lead to the damage of multipliers, gear teeth, casings of the drive and output shafts, and flexible couplings that connect other assemblies of hydropower plants. Figure 7a shows the damage to the flexible coupling type Flender ARPEX K430 series, which is a kinematic connection to the flywheel. The periphery of the flange is distorted. Figure 7b shows the damage on the flexible coupling type Flender N-EUPEX series A 480, which is a kinematic connection to the turbine. Figure 7c shows the damage to the pinion - broken teeth. Figure 7d shows the damage to the seals and the assembly side cover. These phenomena occurred at all sites after 6 years of operation of hydropower plants. At these locations, gears and damaged parts were replaced several times (Vujković, Žegarac, 2012) (Vujković, Žegarac, 2013). A new multiplier from the German manufacturer Siemens-Flender was purchased last time for one location since a replacement of the damaged parts was not possible.



a) b) c) d)

Figure 7 – Damaged parts of the multiplier of a hydropower plant
Рисунок 7 – Изображение поврежденных деталей мультипликатора ГЭС
Слика 7 – Приказ оштећених делова мултипликатора хидроелектране

Civil engineering professionals perform the recovery of the multiplier foundations. At the base, there are threaded sleeves into which six M30x3x100 screws are fixed thus securing the assembly to the foundation. It happens that, during accidents, the heads of these screws break off. During the dismantling of the multiplier from the foundation for replacing damaged parts or for installing a new assembly, it is important to align the assembly in the 3-D system compared to other assemblies. The alignment is done using laser technology (Easy-Laser). The device manufacturer is the company Damalini AB of Sweden. Below the assembly there are metal sheets of various sizes (Figure 8). If this job is not done properly, system breakage can occur again.

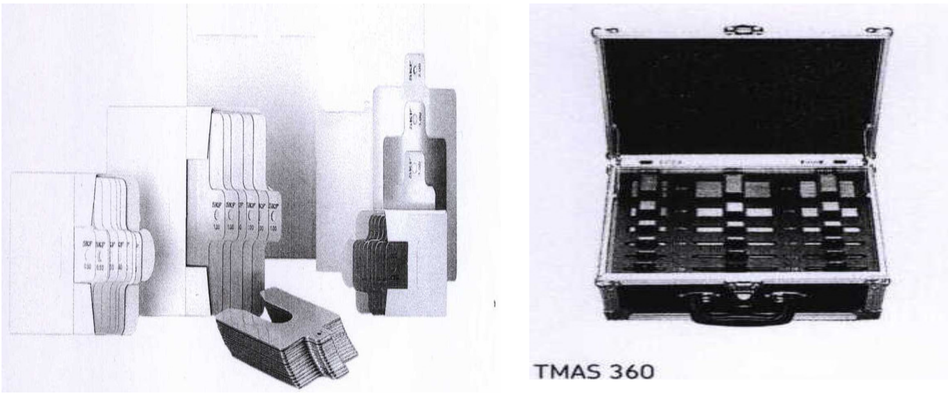
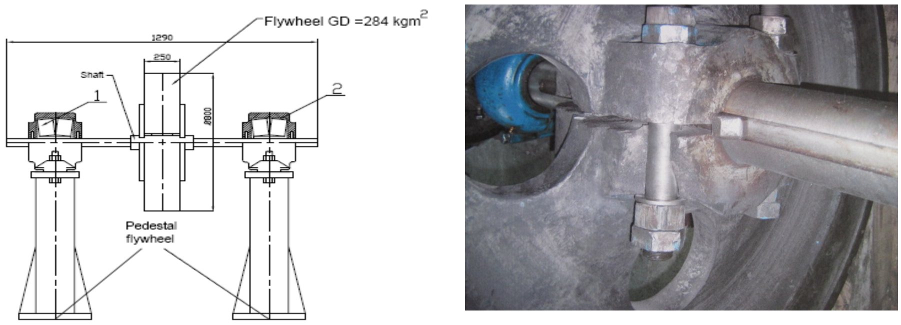


Figure 8 – Set of special metal plates for multiplier adjustement
Рисунок 8 – Комплект опорных пластин для регулировки мультипликатора
Слика 8 – Сет специјалних подложних лимова за центрацију мултипликатора

Figure 9a shows the flywheel with its bearings (cases of rolling bearings and flywheel carriers). The function of the flywheel is to perform dynamic stabilization of the system operation and to eliminate undesirable vibrations that occur due to changes in dynamic processes at different speeds. Due to its inertia when changing the speed of rotation, the flywheel accepts or releases excess energy.

During operation, permanent deformations of the flywheel shaft sleeves (distortion) may occur as well as their excessive wear during improper disassembly (so-called cold dismantling is very bad) of flexible coupling flanges which are rigidly mounted on the sleeves (element overlapping) and secured with wedges. Damage to the flywheel can be caused by improper disassembly of the flywheel shaft. Figure 9b presents a broken flywheel ear, left screw - view from above. For these reasons, professionals should use a device for dismantling and assembling parts of assemblies difficult to detach in mechanical and electrical plants.

In the process of replacing roller bearings on the flywheel, it is very important to align the flywheel in the 3-D system compared to other assemblies. Otherwise, system failures occur. The technical maintenance of flywheel bearings will be described in the chapter Maintenance of plant bearings.



a) b)

Figure 9 – Flywheel of a hydroelectric plant and its bearings
Рисунок 9 – Маховик ГЭС и его подшипник
Слика 9 – Замајац хидроелектране и његово улежиштење

Technical maintenance of electrical circuits, automation and high-voltage systems of a hydroelectric plant

The vital electrical circuit is the plant generator. At the locations of MHPs of the EPCG, generators of Uljanik, Pula and Rade Koncar, Zagreb are installed. Only in one location there was a need to rewind the generator stator, although the systems had been installed during the 1960s. At many locations there was a need to replace rolling bearings of the generator rotor.

Technical maintenance of automation and high voltage installations requires the engagement of experts in the field. Hydropower plant system failures occurred due to the failures of automation during operation. Hydro systems are connected to the main power grid. Automation failures caused a ″crash″ between hydropower plant high voltage and main power grid voltage. In these cases, fractures and severe damage to the rotating assemblies occurred. Fractures occur on the parts of the flexible couplings on the rotating system. In addition, damage on other parts of the machine and electrical circuits is inflicted. Earlier construction of hydropower plants provided that fractures occured at the weakest points in the system. In this case, prevention is obligatory, components that can cause this type of failure must be controlled and replaced if necessary. In contemporary structures of power plants, other protection systems are provided. Additional protective features are incorporated into the automation.

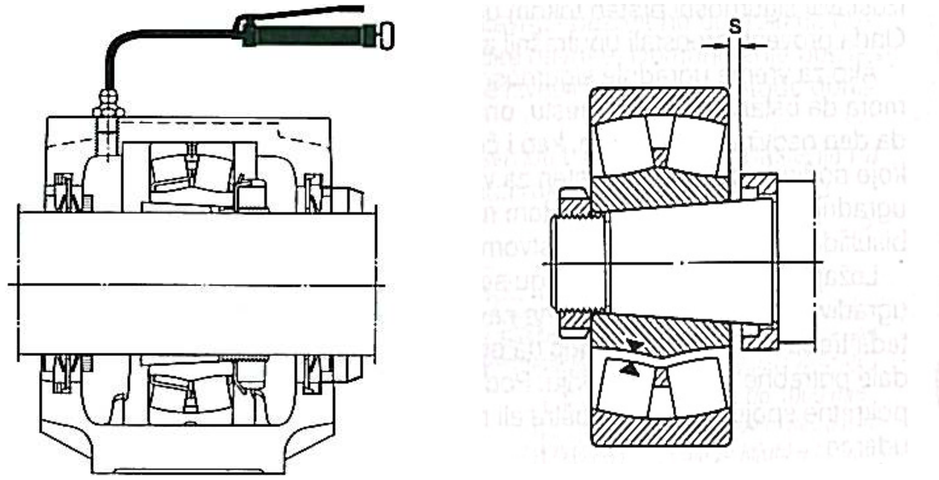
Technical maintenance of mini hydropower plant bearings

The rotation system of mini hydro power plants comprises: a turbine with its shaft in the bearings, rotating parts of toothed gear multiplier- drive shaft and its bearings, output shaft and its bearings and a gear pair, which is a flywheel mounted via its shaft on roller bearings, generator rotor and its bearings, as well as various types of flexible couplings that connect the power assemblies. The flexible coupling type depends on the type and power of a plant.

The turbine shaft is built in the turbine casing on 2-row barrel self-adjustable bearings with conical bushings, Figure 10a. In most cases, bearings SKF 22218 CK + H 318 or SKF 22230 CK + H 3130, with normal internal clearance are fitted. The C-designation indicates the performance of the bearing, the mark K denotes a taper-bearing 1:12. The bearings are lubricated with the prescribed type of grease. When replacing a bearing, its correct installation is very important. These tasks are performed by highly skilled staff (SKF Priručnik za održavanje ležaja, 1998). A particular attention should be paid to the inner radial bearing clearance, Figure 10b. The internal clearance is changed by tightening the nut using a tapered sleeve. The gap sizes shown in Table 2 should be achieved. It is strictly necessary to take into account the engraved markings on the bearings. The inner bearing clearance, C class, is marked as follows:

C1 - internal gap is less than C2,
C2 - internal gap smaller than normal,
C3 - internal gap larger than normal,
C4 - internal gap larger than C3,
C5 - internal gap larger than C4.

It is important to know the size of the cone of the bearing inner ring - whether the cone is 1:12 or 1: 30. In mini hydropower plants, the cone is 1:12.



a) b)

Figure 10 – 2-row barrel bearing with a bushing,
Рисунок 10 – Изображение двухрядного подшипника с втулкой
Слика 10 – Приказ дворедног бачвастог лежаја са чауром

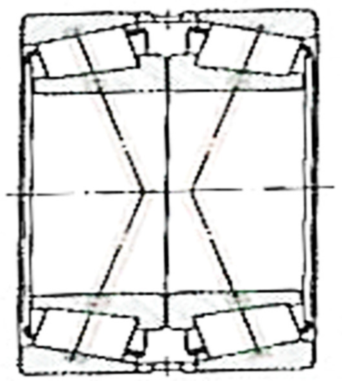
Table 2 – Data for a correct installation of a bearing
Таблица 2 – Данные для правильной установки подшипника
Табела 2 – Подаци за исправну монтажу лежаја

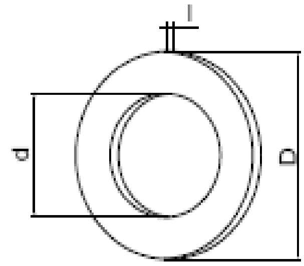
Bearing bore diameter d		**Radial clearance reduction**		**Axial displacement s[1]**				**Minimum allowed retaining radial clearance[2] after installing a bearing with the initial clearance**		
				Cone 1:30		**Cone 1:12**				
over	**including**	**min**	**max**	**min**	**max**	**min**	**max**	**Normal**	**C3**	**C4**
mm		mm		mm				mm		
24	30	0.015	0.020	0.3	0.35	-	-	0.015	0.020	0.035
30	40	0.020	0.025	0.35	0.4	-	-	0.015	0.025	0.040
40	50	0.025	0.030	0.4	0.45	-	-	0.020	0.030	0.050
50	65	0.030	0.040	0.45	0.6	-	-	0.025	0.035	0.055
65	60	0.040	0.050	0.6	0.75	-	-	0.025	0.040	0.070
80	100	0.045	0.060	0.7	0.9	1.7	2.2	0.035	0.050	0.080
100	120	0.050	0.070	0.75	1.1	1.9	2.7	0.050	0.065	0.100
120	140	0.065	0.090	1.1	1.4	2.7	3.5	0.055	0.080	0.110
140	160	0.075	0.100	1.2	1.6	3.0	4.0	0.055	0.090	0.130
160	160	0.080	0.110	1.3	1.7	3.2	4.2	0.060	0.100	0.150
180	200	0.090	0.130	1.4	2.0	3.5	5.0	0.070	0.100	0.160

Bearing bore diameter d		Radial clearance reduction		Axial displacement s[1]				Minimum allowed retaining radial clearance[2] after installing a bearing with the initial clearance		
				Cone 1:30		Cone 1:12				
over	including	min	max	min	max	min	max	Normal	C3	C4
mm		mm		mm				mm		
200	225	0.100	0.140	1.6	2.2	4.0	5.5	0.080	0.120	0.180
225	250	0.110	0.150	1.7	2.4	4.2	6.0	0.090	0.130	0.200
250	260	0.120	0.170	1.9	2.7	4.7	6.7	0.100	0.140	0.220
280	315	0.130	0.190	2.0	3.0	5.0	7.5	0.110	0.150	0.240
315	355	0.150	0.210	2.4	3.3	6.0	6.2	0.120	0.170	0.260
355	400	0.170	0.230	2.6	3.6	6.5	9.0	0.130	0.190	0.290
400	450	0.200	0.260	3.1	4.0	7.7	10	0.130	0.200	0,310
450	500	0.210	0.280	3.3	4.4	8.2	11	0.160	0.230	0.350
500	560	0.240	0.320	3.7	5.0	9.2	12.5	0.170	0.250	0.360
560	630	0.260	0.350	4.0	5.4	10	13.5	0.200	0.290	0.410
630	710	0.300	0.400	4.6	6.2	11.5	15.5	0.210	0.310	0.450
710	600	0.340	0.450	5.3	7.0	13.3	17.5	0.230	0.350	0.510
600	900	0.370	0.500	5.7	7.8	14.3	19.5	0.270	0.390	0.570
900	1000	0.410	0.550	6.3	8.5	15.8	21	0.300	0.430	0.640
1000	1120	0.450	0.600	6.8	9.0	17	23	0.320	0.480	0.700
1120	1250	0.490	0.650	7.4	9.8	18.5	25	0.340	0.540	0.770

[1] Applicable only for solid steel shafts.
[2] Retaining clearance is checked in the cases when the initial internal radial clearance is in the lower half of the tolerance range and when there are significant temperature differences between two bearing rings during operation. Retaining clearance values must not be lower than the minimum values given in the Table.

A control of the internal radial clearance of a bearing is carried out with measuring ballots by the prescribed methodology. If the clearance is less than the required clearance, the bearing will overheat. If the gap is larger, the bearing will also overheat and the rotating system will vibrate. In some variants of turbine housings, it is not possible to control lubrication. There is no inspection opening and it cannot be seen whether the bearing is filled with the right amount of grease. There was a case where the bearings were not sufficiently lubricated, since the inlet tubes supplying grease into the bearing were clogged. Control was possible to be done only by examining how much grease was left in the hand grease nipple for lubrication. Even that was not satisfactory. There is a possibility that the grease feed tube cracks and grease goes inside the turbine housing. As a result, the bearing on the conical bearing sleeve was tourned. A rapid intervention of the operating personnel at the plant prevented the system failure. Taper roller bearings were built into the toothed multiplier. At the site of Podgor, two bearings marked SKF 32034 X were built on the drive shaft of the multiplier and two bearings marked SKF 32226 J2 on the output shaft. These bearings were paired and they had a pre-defined axial internal clearance of 0.310 to 0.370 mm and 0.240 to 0.280 mm, respectively (SKF Priručnik za održavanje ležaja, 1998), These bearings were installed by the principle ″forehead to forehead″ (Figure 7c and Figure 11a). The gaps were adjusted by installing shim rings under the bearing side caps of different sizes and thicknesses, Figure 11b. If the gap is not within the prescribed limits, this leads to an eccentric shaft rotation, dynamic imbalance, overheating of bearings, shocks and vibrations in the rotation system. If the clearance is not within the prescribed limits, this results in system failure. Bearings are lubricated with gearbox oil TOTAL CARTER gradation EP 320 (France) and INA EPOL (Croatia) gradation 220. Since the assembly works at high temperatures, oil in the multiplier housing is water cooled through the spiral tubes placed at the bottom of the housing.





a) *b)*

Figure 11 – Mounting of taper roller bearings and adjusting the axial clearance
Рисунок 11 – Установка конических роликовых подшипников и регулировка осевого зазора
Слика 11 – Уградња коничноваљкастих лежајева и подешавање аксијалног зазора

The hydropower plant flywheel is mounted on two self-adjusting barrel bearings with conical bushings, marked SKF 22220 CK + H 320 and SKF 22222 + H 322. The bearings are installed in the bearing housing type SKF SN 520 or SKF SN 530 (Figure 12). Two rings, marked SKF FRB 12/180 and SKF FRB 17/270, will be installed in the bearing housing to the side of the turbine, fixing the outer bearing ring and preventing the axial movement of the entire rotating system of the hydro power plant - ″fest lager″ (see the bearing housing SKF SN 520 or SKF SN 530, left side flywheel in Figure 9a, position1). In the bearing housings SKF SN 520 and SKF SN 530, the bearings are lubricated with the prescribed grease. The amount of grease is 0.70 kg and 1.80 kg.

The rings for bearing fixing - floating bearing are not installed in the bearing housing towards the generator, Figure 9a, pos. 2. The bearing allows the thermal dilatation of the entire rotating system of the plant. This is a very important rule in the installation of such bearings of rotation machines. So, a ″fest-lager″ is always on the driving side, and a floating bearing - ″los-lager″ on the output side. Many technicians were installing rings for axial fixing into both types of bearing housings, so bearings overheated or they were installing rings on the output side. The bearing housing is tightened by bolts, with a prescribed torque (SKF Hauptkatalog, 2007, pp.1031-1066). The adjustment of the inner radial clearance is carried out using the same methodology as in turbine bearings. Lubrication and replacement of the bearing is carried out by dismantling the top cover of the bearing housing and the bearing is lubricated manually. Grease is set within the bearing on one side and the other side through the rollers. Grease is not put into the housing itself.

The method of bearing lubrication is important. The same type of grease used previously in the bearing is always used. Some types of grease lose their properties when mixed with other types of grease. Grease types that are not compatible (different bases (Ca) (Na), (Li) or a mixture of grease (Li / Ca) should never be mixed. High-quality lubricating greases are used such as those of SKF or Shell. Grease Shell Alvania Grease G3 is of extremely high quality and is often used for lubrication.

The bearing housing is not washed with chemical agents; it is all done by hand. The instructions for bearing lubrication should be carefully followed. The amount of grease put into bearings is very important. If there is no prescribed amount of grease, the following formula for determining the amount of grease is used:

$$Ga = 0.005 \cdot D \cdot B$$

where the mark *Ga* is grease content (in grams), D is the outer diameter of the bearing (mm) and B is the total width of the bearing (mm).

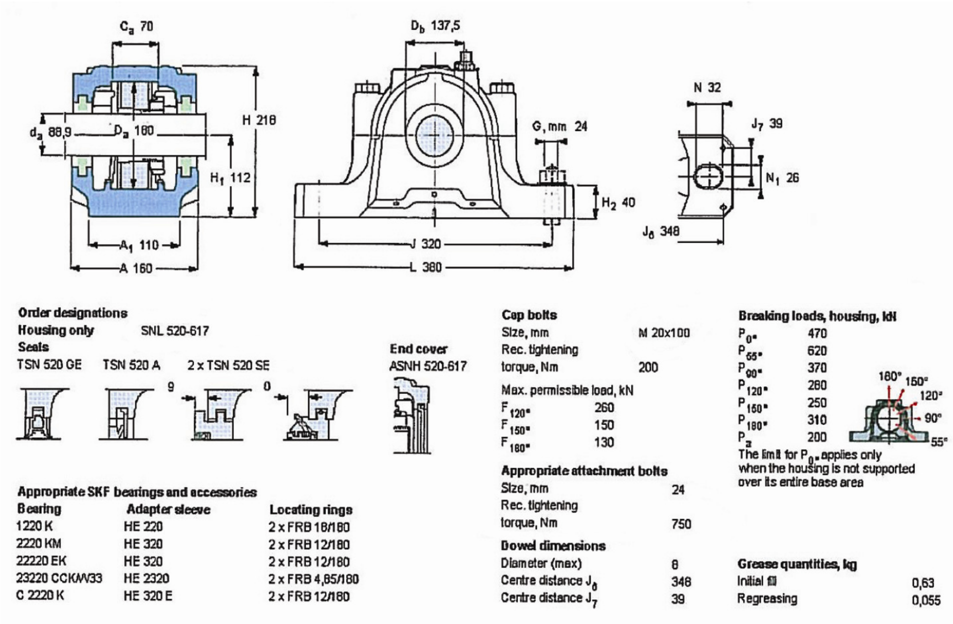


Figure 12 – Construction of the bearing housings SKF SN 520 and SKF SN 530
Рисунок 12 – Изображение конструкции корпуса подшипника SKF SN 520 и SKF SN 530
Слика 12 – Приказ конструкције кућишта лежаја SKF SN 520 и SKF SN 530

The rotors of the hydroelectric power generator of 600 KW rests on two ball bearings marked SKF 6322 / $C_{4\,a}$ at the end of the generator and SKF 6326 / C_4 on the side towards the flywheel. In the hydroelectric power plant of 450 KW, at the end of the generator, there is an SKF BS 6319 / C3 bearing built in, and on the side of the flywheel there is an SKF 6324 / C_3. (Figure 13). These bearings have increased radial clearance due to increased amounts of heat radiated by the generator during operation. Generator bearings for hydroelectric power plants of greater power have a greater radial clearance C_4. If radial clearances were smaller, bearings would ″scuff″. The bearings are lubricated with a hand grease gun. In the generator housing, there are control openings for controlling the quantity of grease or for the exit of excess grease.

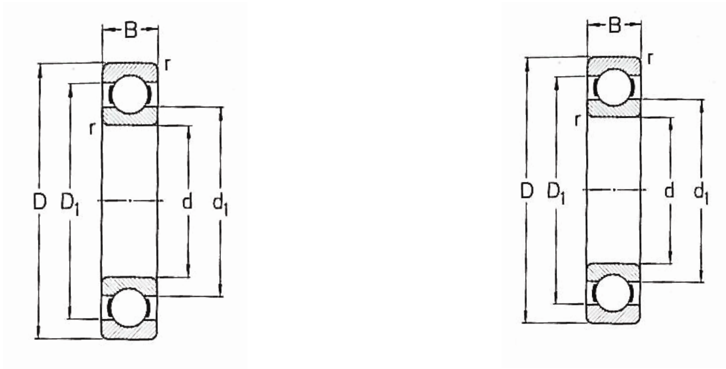


Figure 13 – Ball bearings of the generator of increased radial clearance C_3 and C_4
Рисунок 13 – Изображение шариковых подшипников для генераторов с увеличенными радиальными зазорами C_3 и C_4
Слика 13 – Приказ кугличних лежајева генератора повећане радијалне зрачности C_3 и C_4

Slide bearings in mini hydropower plants (vertical hydropower plants) are lubricated by lubricating oil of the prescribed quality and gradation. The sliding layer has a thickness up to 30 mm, and it is applied to the outer two-piece steel sleeve of the bearing.

Technical maintenance of flexible couplings in mini hydropower plants

In the mini hydropower plants of the EPCG, flexible couplings of well-known manufacturers such as German companies Siemens and Flender-Stromag are installed. In some hydropower plants, between the turbine and the multiplier, there are Flender A 480 N-EUPEX couplings (Figure 14) and Flender RWN 710 ones (Figure 15). The numbers of 480 and 710 indicate the outer diameter of the coupling in mm.

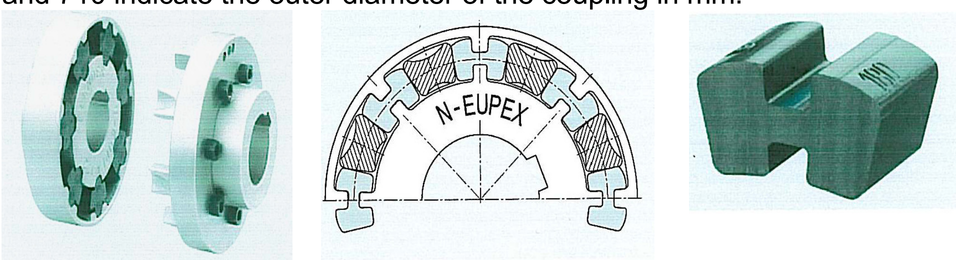


Figure 14 – Flexible coupling type Flender N-EUPEX version A 480
Рисунок 14 – Эластичная муфта Флендер N-EUPEX тип A 480
Слика 14 – Еластична спојница типа Flender N-Eupex, изведба A 480

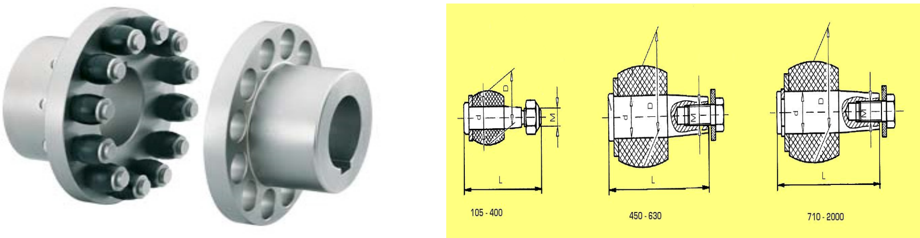


Figure 15 – Set of a flexible coupling type RWN version Flender RUPEX 710
Рисунок 15 – Комплект эластичных муфт RWN тип Флендер RUPEX 710
Слика 15 – Комплет еластичних спојница типа Flender Rupex, изведба RWN 710

On the side of the turbine shaft, the hub left side is mounted while the hub right side of the coupling is mounted on the multiplier drive shaft (see Figure 15). The flexible connection consists of rubber elastic elements (usually 10 pieces make a set), H-shaped or barrel-shaped. There are various hardness values of rubber elements and they are marked by different colors. The standard hardness value of 80 Shore (A) is used here, marked in blue.

Once a year, the correctness of the rubber elements is checked in accordance with the prescribed methodology (Figure 16). The measurement value ΔSv is obtained by measurements taken while the plant does not function. Two marks are made at the same level on the coupling hubs, and then one coupling hub is held fixed while the other is rotated manually. The measured value of ΔSv for the N-EUPEX coupling has a maximum value of ΔSv=15.5 mm (Technische dokumentation Flender elastische Kupplungen N-Eupex, Bauarten A und B, pp.1-36, Bocholt, 2003). If the value is higher, the rubber elements must be replaced immediately. Rubber elements are changed regularly every 3 years, due to the natural aging of rubber. Elements must be changed if deformed, damaged and if they have cracks, which may cause failure of mechanical assemblies, which has already happened in practice.

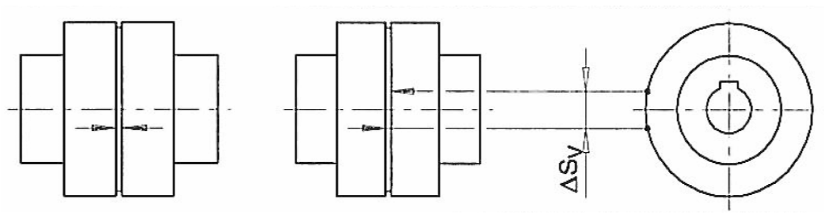


Figure 16 – Testing the rubber elastic elements of the couplings Flender N-480 and A-EUPEX RUPEX RWN 710
Рисунок 16 – Тестирование резиновых эластичных муфт типа N-480 и A-EUPEX RUPEX RWN 710
Слика 16 – Провера исправности гумених еластичних елемената спојница типа Flender N-Eupex A 480 и Rupex RWN 710

During dismantling and assembling the hydroelectric power plant assemblies, system assemblies alignment norms should be strictly observed. It is necessary to carry out measurements, calculations and comparisons of the measured values and the calculated values. The alignment of assemblies is carried out in the 3-D system. For these types of flexible couplings, a similar technology is prescribed for overhaul and control calculations of deviations during installation. Figure 17 presents the checking of values S_{1min} and S_{1max}, axial deviations ΔKa, angular deviations ΔKw and radial deviations ΔKr.

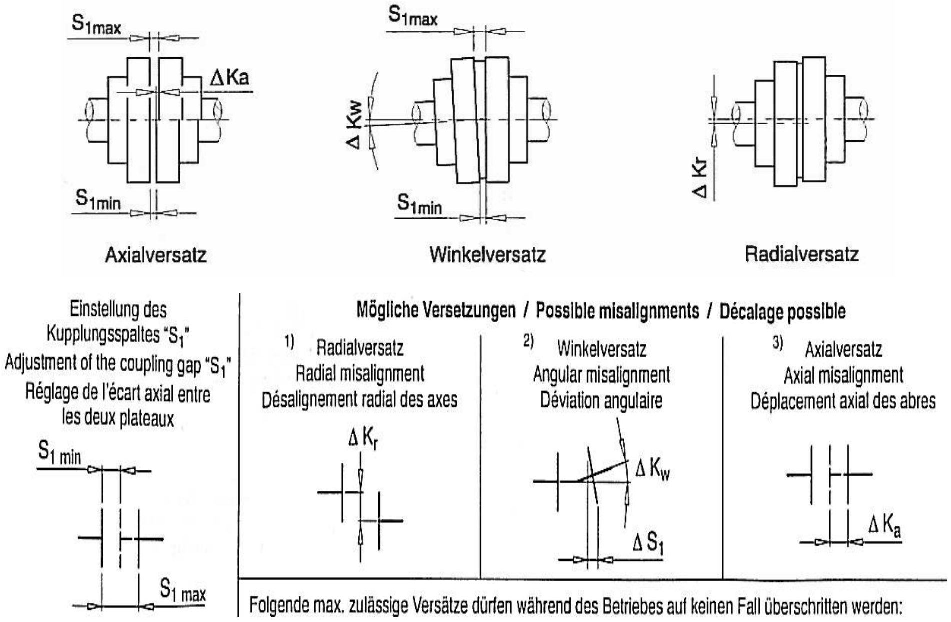


Figure 17 – Display and calculations of discrepancies of elastic couplings in the 3-D system
Рисунок 17 – Изображение и расчет расхождений эластичных муфт в системе 3-D
Слика 17 – Приказ и прорачун одступања еластичних спојница у 3-D систему

For A480 N-EUPEX elastic coupling the values S_{1min}=5 mm and S_{1max}=10 mm are prescribed. The permitted values of axial deviations ΔK_{azul}, radial deviations ΔKr_{zul}, angular deviations ΔKw_{zul}, and the difference between the maximum and minimum clearance $\Delta S_{1zul}=S_{1max} - S_{1min}$ are prescribed. The values of clearances of these gaps are: $\Delta Kr_{zul}=\Delta S_{1zul}=\Delta K_{azul}$=1.1 mm, ΔKw_{zul}=0.11° and for RUPEX coupling RWN 710 - S_{1min}=5 mm, S_{1max}=9 mm and the maximum permissible deviation values $\Delta Kr_{zul}=\Delta S_{1zul}=\Delta K_{azul}$=1.1 mm, ΔKw_{zul}=0.12°. The measured values of deviations after the overhaul had far lower values compared to the calculated values.

The calculation of deviations in the 3-D system is carried out according to the formulas:

$$\Delta Kr_{zul./perm./aut.} = \Delta S_{1\,zul./perm./aut.} = \Delta K_{a\,zul./perm./aut.} = (0.1 + \frac{d_a}{1000}) \cdot \frac{40}{\sqrt{n}}$$

The calculation of the angular deviations is carried out according to the formula:

$$\Delta Kw_{zul}\ in\ Rad = \frac{\Delta S_{1\,zul}}{d_a}$$

$$\Delta Kw_{zul}\ in\ Grad = \frac{180}{\pi} \cdot \frac{\Delta S_{1\,zul}}{d_a}$$

where the mark *da* - means the outer diameter of the coupling, and n is the number of revolutions per minute of the turbine shaft on which a flexible coupling is mounted.

For each type of flexible couplings, the equipment manufacturers prescribed permitted values of all deviations and values for screw tightening torques in flexible couplings (Elastische Kuppllungen Flender Bauart RUPEX RWN, 2003, pp.1-30), (Betriebsanleitung BA 3100 DE 07.03, 2003, pp.1-36).

The Periflex flexible couplings connecting the drive system of the power plant and the hydropower plant generator do not require special maintenance. The coupling is presented in Figure 18. The producer of couplings is the German company Flender. Couplings used to be produced by the company Pobeda, Novi Sad. In the process of replacement, the installation dimension marked with the letter ″O″ must be maintained and the tightening of the clamping screws must be carried with a prescribed torque. Rubber elastic elements of the coupling should be changed in accordance with the maintenance instructions (Antriebtechnik von Stromag, 1996, pp.1- 40).

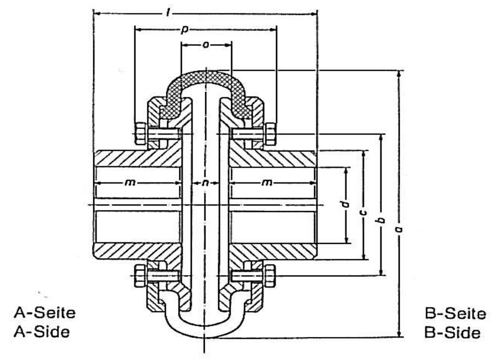


Figure 18 – Flexible coupling of Stromag Periflex Version PNA type, size 225 R and 426 R
Рисунок 18 – Эластичные муфты Stromag Periflex тип PNA, размер 225 R и 426 R
Слика 18 – Еластичне спојнице Stromag типа Periflex, изведбе PNA, величине 225 R и 426 R

Flexible couplings Flender type ARPEX series K 430, with the outer diameter ∅270 or ∅320 mm, mounted in the hydropower plants in the EPCG, are particularly highly sensitive mechanical components in the system of hydropower plant maintenance. Couplings are installed in the system drive, between the multiplier and the flywheel (drive side of the system) and on the output side (the other side of the system), between the flywheel and the generator. A set of couplings is shown in Figure 19a. In Figure 19b, tolerance measures when installing the set of couplings are marked. The values S_{1min}, S_{1max} are measured in 6 measurement points after the assembly. Before the assembly, it is very important to measure the dimensions of flanges (Figure 19a, pos.1, lamellar packs, pos. 2 and shaft couplings pos. 3) in order to achieve the required measures in 6 measurement points, according to the installation instructions. Unacceptable radial deviations of the flange and the shaft present a particular problem. They create large centrifugal forces and break the plate packs. Screw holes in the flanges and the shaft in conjunction with bolts must be within the tolerances of *"gentle folding"*.

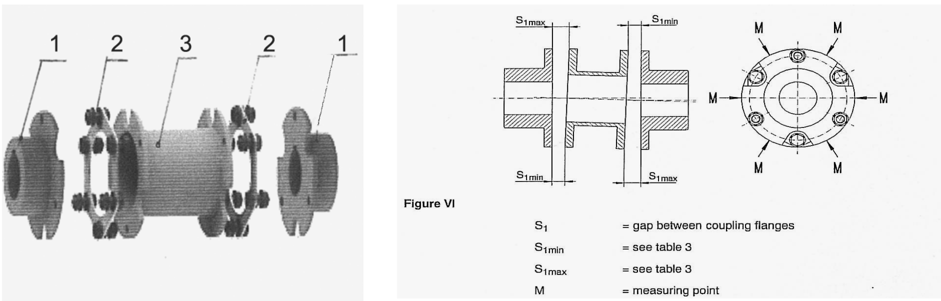
The dimensional tolerances of the intermediate shaft, deformed during operation, must be controlled in particular. If the couplings are mounted incorrectly, there occurs a system breakdown. The axial direction is particularly sensitive, if coupling lamellar packs are stretched due to incorrect installation, in the longitudinal axis of the rotation system. The control calculation and the measurement of tolerances after the installation of the coupling set are done according to the manufacturer's technical documentation (Technische dokumentation Flender Betriebsanleitung BA 8700 DE 08.95, 1992). The thickness of the lamellar pack S1 for the coupling of ∅270 mm is S_1=23 mm and the prescribed values for S_{1min} =22.4 mm and S_{1max} =23.6 mm. For the coupling outer diameter of ∅320 mm, the thickness of lamellar packs is S_1=27 mm and the prescribed values for S_{1min}=26.3 mm and S_{1max}=27.7 mm. Figure 21 shows the variables taken into the calculation of the allowed deviations. The value L is the average distance between the lamellar packs, expressed in mm. S means the distance between the flanges of flexible couplings expressed in mm, Figure 21b. The value L is calculated using the formula:

$$L = S - S_1$$

If the axial distance between the flanges is ΔKa=0 mm, the values for ΔKw are read in the manufacturer tables, then ΔKw = 0.7°. If ΔKa=0.6 mm the value ΔKw=0.5°. for couplings of ∅270 mm and ∅320 mm, the value L is in the range L from 194 to 220 mm. In this case, the maximum values are calculated using the formula:

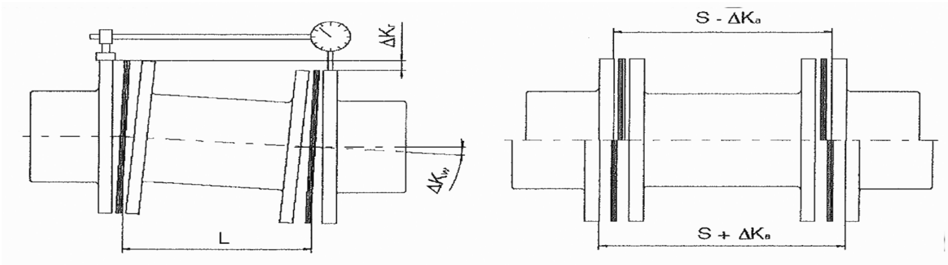
$$\Delta K_r = tg(\Delta K_W \cdot L)$$

and they are ΔKr =1 to 2 mm. In our assembly procedures, the ΔKr values amounted to a maximum of ΔKr=0.4 mm, indicating a very high quality of assembly.



a) b)

Figure 19 – Display of flexible couplings ARPEX Flender series K 430 sizes 80 to 820
Рисунок 19 – Изображение эластичной муфты типа ARPEX Флендер серии K 430 размером от 80 до 820
Слика 19 – Приказ еластичне спојнице типа Arpex Flender, серије K 430, величине 80 до 820

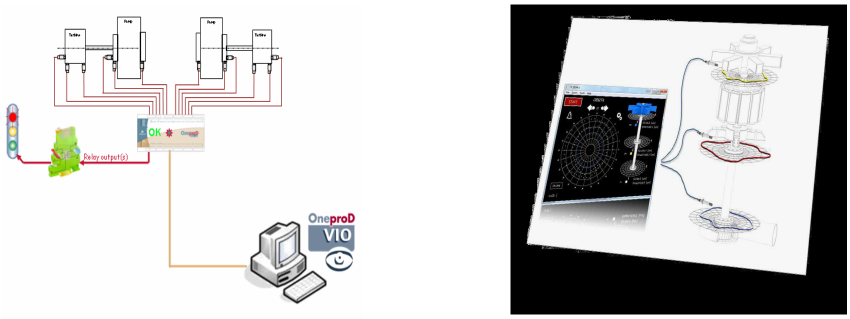


a) b)

Figure 20 – Measurement of variations in the 3-D system in flexible couplings Flender ARPEX series K 430
Рисунок 20 – Измерение расхождений в системе 3-D эластичной муфты типа Flender ARPEX серии K 430
Слика 20 – Мерење одступања у 3-D систему на еластичним спојницама типа Flender Arpex, серије K 430

Technical diagnostics and monitoring systems in mini hydropower plants

Mini hydropower plants built in the past did not possess modern measuring equipment and devices. Modernization of measuring techniques and systems has become more and more advanced. Nowadays, regardless of the installation time, many systems for monitoring operating parameters have been subsequently built on many systems. Instruments and gauges showing and measuring many dimensions and operating parameters have been built in for temperature, pressure, water flow, vibration levels and electrical parameters. On-Line Monitoring systems that consistently show measured values were installed on some hydropower plants (Žegarac, 2005). On much older systems, measurements of functional parameters are carried out periodically - Off-Line-Systems. Such measurements are recommended every 15 months. It is very important to measure vibration parameters on mechanical assemblies and to analyze them. There are a lot of possibilities for data analysis in modern measurement systems, such as data archiving during the plant operation period, etc. Figure 21a presents a modern monitoring system in a mini hydropower plant at one location. (Žegarac, 2005). Two hydro units are in parallel operation in a system. There is a possibility that the hydro aggregates are stopped in case of alarm messages if some of the measured values are not within the permitted limits. The system has an automatic control and monitoring of technical safety. Figure 21b shows modern monitoring for measuring relative vibrations and the degree of wear of sliding bearings (Žegarac, 1989), (Žegarac, 1993).



a) b)

Figure 21 – On-line monitoring system and the monitoring system for sliding bearings
Рисунок 21 – Изображение онлайн системы мониторинга и системы мониторинга по подшипникам скольжения
Слика 21 – Приказ on-line мониторинг система и мониторинг система за клизне лежајеве

Conclusion

This paper describes the author's experience in performing technical maintenance of complex energy systems, mini hydropower systems in particular. Mini hydroelectric power plants are renewable sources of energy. At the present time and in the future, they have significant advantages compared to other energy systems. This paper presents an analysis of many causes of malfunctions, faults, operation failures and system failures that occur on some machine parts, electrical circuits or other parts of installations and equipment that are integral parts of power plants and play an important role in the proper functioning of the system. Examples of failures, accidents and causes of their occurrence are displayed in detail. The main goal is to perform preventive and planned technical maintenance of the system. The paper shows numerous examples of how to use technical documentation of equipment manufacturers which contains prescribed standards of technical maintenance of systems. Major damage to systems may occur due to neglecting or not knowing the instructions, standards or technical documentation. Some energy systems were installed long time ago so end-users do not have complete technical documentation, which makes serious problems during technical maintenance. Thanks to valuable experience and knowledge of our qualified personnel in the maintenance of other complex systems such as large hydro and thermal power plants and systems for process industries, this part of the problem is successfully addressed. Such knowledge and experience are gladly communicated to technical staff of the system end users. Technical training is particularly important for persons responsible for systems in operational work so that they can react in time in case of an extraordinary event. Previous experience and knowledge show that many phenomena can be predicted in advance. The expertise and training of the personnel performing overhaul is of particular importance for high quality performed overhaul. In addition, they must be equipped with professional tools, accessories and other equipment for high quality overhaul. Such complex systems do not allow improvisations in performing overhaul; one mistake leads to several new problems for which there are certain consequences in the plant exploitation (known cases from practice). It is especially important to use modern measuring equipment, and to measure some parameters in the plant itself. Measuring equipment can be permanently installed (use of modern monitoring systems) or measuring equipment can be transferred so certain parameters are periodically measured on the spot where the system is installed. Some failures and faults cannot be predicted. At many locations, there are energy systems the exploitation period of which has been expired. A particular problem is the production and procurement of original spare parts. The process takes a long time so the systems are out of use. End users must plan a purchase of new mini hydropower plants.

In the current technical maintenance of mini hydropower plants, significant results have been achieved. Accidents, system faults and failures are prevented, which is very important, since these systems are of a production character. It is particularly important that systems operate properly in the season when there is large influx of water into hydroelectric power plants.

References

- Antriebtechnik von Stromag, D 800 11.83, Elastische Kupplungen, 1996. Unna, Deutschland: Stromag, pp.1-40.

- Betriebsanleitung BA 3100 DE 07.03, Elastische N-Eupex und N-Eupex-DS Kupllungen der Bauarten A, B und ADS, BDS, 2003. Bocholt, Deutschland: Flender, GmbH, pp.1-36.

Milovanović, Z., 2014. Termoenergetska postrojenja - tehnološki sistemi, projektovanje i izgradnja, eksploatacija i održavanje. Univerzitet u Banja Luci - Mašinski fakultet (in Serbian).

- Razvoj, projektovanje i proizvodnja radnog kola Peltonove turbine, 2010. Beograd: Lola institut (in Serbian).

- SKF Priručnik za održavanje ležaja, 1998. Publikacija 4100/I YU reg.br. 50.3000.1998-07, pp.144-145.

- SKF Hauptkatalog, 2007. Sweden, pp.1031-1066.

- Tehnička dokumentacija za elektro hidraulični regulator tipa EHR-80 za male hidroelektrane, 1968. Ljubljana: Novum - Centar za tehnološke inovacije., pp.1-12.

- Tehnička dokumentacija firme Flender, 1975. Nemačka.

- Tehnička dokumentacija za MHE, 1980. Podgorica: Eelektroprivreda Crne Gore.

- Technische dokumentation Flender Betriebsanleitung BA 8700 DE 08.95, 1992. Bocholt, Deutschland: Flender, GmbH.

- Technische dokumentation Flender elastische Kupplungen N-Eupex, Bauarten A und B, 2003. Bocholt, Deutschland: Flender, GmbH, pp.1-36.

Vujković, R., & Žegarac, N., 2012. Razvoj, projektovanje i proizvodnja zupčastog para za multiplikator u MHE Podgor. Crna Gora. Beograd: Alatnica Lazarević.

Vujković, R., & Žegarac, N. 2013. Razvoj, projektovanje i proizvodnja zupčastog para za multiplikator u MHE Rijeka Crnojevića - Crna Gora. Beograd: Alatnica Lazarević.

Žegarac, N., 2005. Projekat monitoring sistema za potrebe EPCG-MHE.

Žegarac, N., 1989. Dijagnostika kliznih ležajeva u dizel motorima. Zagreb: Sveučilište u Zagrebu - Fakultet strojarstva i brodogradnje.

Žegarac, N., 1993. Postupak i uređaj za određivanje zazora u kliznim ležajevima, merenjem dinamičke putanje glavnih rukavaca kolenastog vratila motora sa unutrašnjim sagorevanjem. Patent- br. 48216 - P-640/93. Beograd: Zavod za intelektualnu svojinu.

Žegarac, N., 2016. Application of modern monitoring systems in mini hydropower plants. Vojntehnički glasnik / Millitary Technical Courier, 64(4), pp.1102-1118. Available at: http://dx.doi.org/10.5937/vojtehg64-9936.

ПОВЫШЕНИЕ КАЧЕСТВА ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ СИСТЕМ МИНИ ГЭС И АНАЛИЗ ПРИЧИН ИХ ВЫХОДА ИЗ СТРОЯ, СБОЕВ И АВАРИЙ

Никола П. Жегарац
Сербская академия изобретателей и ученых, г. Белград, Республика Сербия

ОБЛАСТЬ: машиностроение, энергетика, электротехника, электроника, контроль и надзор, техническая диагностика
ТИП СТАТЬИ: оригинальная научная статья
ЯЗЫК: английский

Резюме:

В статье представлен многолетний опыт работы, связанный с деятельностью по техническому обслуживанию машин и электроустановок. Приведен анализ главных причин неисправностей, сбоев и аварий, случающихся на мини-ГЭС. В статье предлагается внедрение системы на Мини ГЭС, которая будет способствовать улучшению качества технического обслуживания энергоблоков: турбинного блока с регулятором, механических узлов (мультипликатор и маховик ГЭС), эластичных муфт, соединяющих узлы установки, смазочных систем, автоматизации и высоковольтных установок. В статье также представлен краткий обзор возможностей применения технической диагностики и мониторинга систем на мини-ГЭС.

Ключевые слова: техническое обслуживание, мини ГЭС, отказы, сбои, аварии, подшипники, эластичные муфты, механические узлы, электрические схемы.

УНАПРЕЂЕЊЕ ТЕХНИЧКОГ ОДРЖАВАЊА СИСТЕМА МИНИ-ХИДРОЕЛЕКТРАНА, АНАЛИЗА УЗРОКА НЕИСПРАВНОСТИ, КВАРОВА, ОТКАЗА У РАДУ И ХАВАРИЈА

Никола П. Жегарац
Српска академија изумитеља и научника, Београд, Република Србија

ОБЛАСТ: машинство, енергетика, електротехника, електроника, аутоматско управљање и надзор, техничка дијагностика
ВРСТА ЧЛАНКА: оригинални научни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

У раду су приказана дугогодишња искуства на пословима техничког одржавања машинских и електропостројења. Извршена је анализа многих узрока неисправности, кварова, отказа у раду и хаварија, који се појављују на мини-хидроелектранама. Системи мини-хидроелектрана разматрани су са аспекта унапређења техничког одржавања по функционалним целинама: турбински склоп са регулатором турбине, механички склопови (мултипликатор и замајац електране), еластичне спојнице које повезују склопове постројења, електросклопови, системи подмазивања, аутоматика и високонапонска постројења. Приказан је кратак осврт на могућности примене техничке дијагностике, односно мониторинг система на мини-хидроелектранама.

Кључне речи: техничко одржавање, мини-хидроелектране, кварови, неисправности, хаварије, лежајеви, еластичне спојнице, машински склопови, електросклопови.

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