Design and Implementation Experience with Oil Free Ecological Kaplan Runners

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Introduction

With a classic oil-filled Kaplan runner hub, large quantity of oil in the hub are isolated from the contact with river water only by the runner blade seals, therefore a high risk of oil contaminating the river exists in case of any seal damage or failure.

Nowadays, many hydro power plant owners are deciding to implement ecological, oil free Kaplan runner solutions into their power plants. Nordic countries are among world leaders in this area but other countries follow the lead as well. The transition from oil filled runner mechanism toward ecological solutions is dictated by legislation requirements as well as customer high environmental consciousness with the main goal of minimizing the risk and eventually to eliminate the possibility of oil leak into the river.

Since 2005 Litostroj Power installed above 30 ecological runners. Main principle of runner mechanism remains the same compared to oil filled runners; the differences; however, could be seen in the design of the details. In general, two ecological runner solutions can be observed; runners with "water-filled" hub and runners with "air-filled" (empty) hub.

There are many challenges to be dealt during initial design and development of an ecological runner from operational and life expectancy criteria. Designers are challenged to choose correct materials that would operate in oil-free environment that in general does not protect the materials against corrosion, reduces the lubrication features etc.

Customers demand new, better, more reliable and customized solutions regarding reliability, monitoring, maintenance and design features. The design has been evolving ever since the implementation of the first ecological runner, starting with only slightly adapted design of an oil filled runner toward dedicated oil free solution that is in use nowadays.

1. Meeting the challenges

During a design evolution of an oil-free runner, several challenges were encountered. Some of the challenges were identified and solved during design stage, however certain experiences were gathered later during start-up and operation of the units.

Among the biggest encountered challenges were (i) friction and wear in bearings and seals, (ii) different types of corrosion due to absence of protecting environment, (iii) the choice of corrosion protection, and (iv) the choice of materials in the runner design.

When considering customers' requirements and limitations regarding materials used there is no uniform solution for the design. Various types or combinations of chosen materials and components, when considered in hostile environment, in many cases change the behavior of the bearings and seals, making a process of designing optimal solution even more complex. Therefore, innovative methods had to be implemented for the task to be carried out completely and optimally.

A team of design engineers and technologists with different background knowledge was formed to cover the process from bidding phase through mechanical design, shop assembly and site installation phase to commissioning; in order to deal with the design challenges of runners and particularly oil free runners. All engineers gained insight into each other's field of expertise through brainstorming and education sessions. Collective knowledge from various phases over entire lifecycle of runners proved to be an excellent asset. Over the last years, we formed a complete and competent team for finding solutions and improvements for the runner as a key component of Kaplan turbine.

During the research process a knowledge database was formed, containing information on mechanical, physical and chemical properties of materials that were, are, or potentially will be used in our oil free runners. The database is alive and constantly growing with information gathered based on cooperation with manufacturers of materials and components as well as internally conducted research and testing.

1.1. Material properties data

While values and data stated in catalogues or data sheets are usually correct, they can often be misleading. Namely, the catalogue values are usually average values stated for only certain operating conditions. As an example, for bearing materials, we found out that both the coefficient of friction and wear rate can change significantly over wide operating range of surface contact pressures or within different environment conditions.

In cooperation with several manufacturers, we conducted additional testing to obtain better insight of expected behavior over the operating range and conditions. In many cases testing was mutually defined to obtain required data for our application. In certain cases, testing was conducted or repeated by Litostroj Power to relatively compare materials from different manufacturers and to double check properties obtained from manufacturers themselves.

2. Corrosion issues

Ecological runner hubs filled with pure water or dry runner hubs are prone to many types of corrosion. Many effects of corrosion and their impacts on the safe and reliable operation of the runner mechanism are far more serious than only the loss of material.

In water filled runner hubs, the pure water is a source of corrosion related problems. The problem is mitigated by applying chemical solutions such as adding corrosion inhibitors in the hub water. The corrosion inhibitors effectively neutralize the corrosive effects of wet environments; however, the inhibitors may have impacts on the installed seal and bearing materials.

2.1. Corrosion issues in water filled runners

Most easily observed corrosion in water filled runners, be that demineralized, distilled, deoxidized or normal tap water are galvanic and crevice corrosion. Any type of water quickly becomes an electrolyte and also changes PH value due to corrosion and abrasion in metallic bearings.

With electrolyte present in the water, a galvanic corrosion occurs when the surrounding conductive environment couples two materials with different galvanic potential. Galvanic corrosion affects less noble material of the couple. It is more severe if area ratio between both materials is more in favour of the nobler one. Galvanic corrosion, as presented in Figure 1, can affect large areas and propagate quickly so it can cause severe material loss and can lead to corroded material failure.

Normal tap water is an electrolyte by itself. It is full of minerals like Ca2+, MG2+, Na-, and Cl- making the galvanic corrosion to occur very easily. Conductance of normal tap water is few times higher that of the conductance of distilled or other types of treated water. Nevertheless, treated water types get saturated with minerals/oxygen quite quickly and basis for galvanic corrosion is set as well.

Another type of corrosion often found in water filled ecological runners is crevice corrosion. Crevice corrosion occurs where small gaps exist, e.g. in bearings, under seals, under paint, etc. For crevice corrosion to take place there should be two different electrolyte environments present at a metal surface.

Two different environments in electrolyte are formed due to limited circulation of fluid in crevice itself and much higher circulation of the fluid outside the crevice; aeration of the fluid in the crevice is practically not possible, therefore gradually the environment changes to strongly acid environment that makes the crevice corrosion to occur.

Fig. 1. Galvanic corrosion; removal of material on les noble material and deposits on more noble material

One type of crevice corrosion that is usually found is pitting, shown on Figure 2. Pitting can on one hand lead to degradation of bearings and sealing solutions before corroded material failure occurs but on the other hand, as is the case with stainless steel, pitting can occur below the surface and corroded material failure can occur before any signs of bearing or sealing problems arise.

Fig. 2. Pitting crevice corrosion on bearing counter surface

2.2. Corrosion inhibitors used in water filled hubs

It was observed that corrosion inhibitors have various side effects in addition to preventing corrosion. Some of side effects in incorrectly chosen components are increased friction, increased wear and degradation of certain bearing and sealing materials.

Many strong corrosion inhibitors are often more or less environmentally unfriendly; however, in case of leakage into the river water the concentration would be very weak and would pose very small to almost no danger to the environment.

When selecting corrosion inhibitors it is important to check the following aspects: ecology, corrosion prevention, Influence on friction and wear behavior of installed sealing and bearing components.

2.3. Corrosion issues in dry runners

Regarding corrosion, dry runners are somehow more unpredictable than the ones filled with water with added corrosion inhibitors. Nevertheless, corrosion issues in dry runner hubs are significantly better controllable than the runners filled with pure water only.

Environment in dry runners in not exactly “a dry condition”. We can expect that runner hubs are humid environments where some condensation can always be present. Indeed, in dry runners crevice corrosion was observed in designs where condensed water was able to fill the crevices. With certain design features, condensation liquid can be prevented to remain within the area of contact between two different materials and thus the possibility of crevice corrosion formation is minimized.

Galvanic corrosion in dry runners is rare due to absence of electrolyte. It can however still occur locally if condensation occurs; however, with proper design the corrosion can be limited to the parts that are not vital for runner mechanism operation.

2.4. Corrosion protection

Corrosion in ecological runners, dry and liquid filled ones, can be more or less successfully avoided by implementing certain design solutions such as (i) using correct materials, (ii) isolating critical material couplings, (iii) avoiding crevices or protecting them, (iv) adding predetermined percentage of a corrosion inhibitor into the water, and (v)design empty runner hub.

Due to different reasons, not all customers are keen on applying certain design solutions such as using inhibitor at all or certain type of inhibitor as additive in the water filled runner hubs. Litostroj Power gained reasonable experience in bearing and sealing behaviour when used with certain types of additives and experience of additive influences on the corrosion protection itself. From this perspective, we are ready to discuss different design solutions and approaches and consult the customer within their needs and requirements. The selected corrosion protection solution just should be taken into account when choosing materials and components for the runner hub and mechanism.

3. Friction and wear of bearing material

Customers are most frequently concerned with wear of material and consequently service lifetime of the equipment or related maintenance needs.

While friction and wear in oil-filled runners is not a big issue and is well under control, the friction and wear in other media strongly depend on materials used and environment in which they operate. Often friction and wear have inverse relationship. But as we have learned this is not always the case.

The bearing friction and wear rate relationship depends on quite a few variables including (i) surface pressure, (ii) sliding layer material, (iii) counter surface material, (iv) temperature, (v) sliding speed, (vi) time, and (vii) medium in the runner hub.

As already pointed out, manufacturer's data is usually very limited and given for one or a few operating points. Therefore, when considering all above-mentioned influential factors there are countless experiments to be conducted to find all data for friction and wear of components of the runner mechanism. There is a possibility to avoid being overwhelmed with experimentation. One is adapting design to a known data range and, where this is not possible, interpolating and extrapolating known data to the desired operation area. Latter is risky and should be avoided or backed up by additional testing.

In recent years, Litostroj Power has been gathering data or conducting tests to obtain data about bearing material behaviour. We tested both metallic as well as synthetic composite type materials over different environment and operational ranges. Results are sometimes expected, but in quite a few cases surprising.

Tests were conducted in different environments covering dry, oil, water and water with different additives. When testing different materials in different environments, or even in different inhibitor concentrations, bearing material behaviour is changing in terms of wear, friction or both. We found out, that not all materials behave in the same manner, showing different sensitivity to different environments.

Another influence turned out to be contact surface pressure that shows different coefficient of friction sensitivity in combination with different environments. On top of that, friction changes over time as well. Mostly it stabilizes close to a certain value, sometimes friction somewhat undulates around a certain value which has to be taken into account during the design.

Each environment influence on the bearing and sealing design is complex and needs to be studied in detail before implementation.

Figure 3 shows correlation between surface pressure and friction for given material and medium. As it can be observed, the correlation is far from inverse. Results for same correlation with different medium are different which can mean design difference.

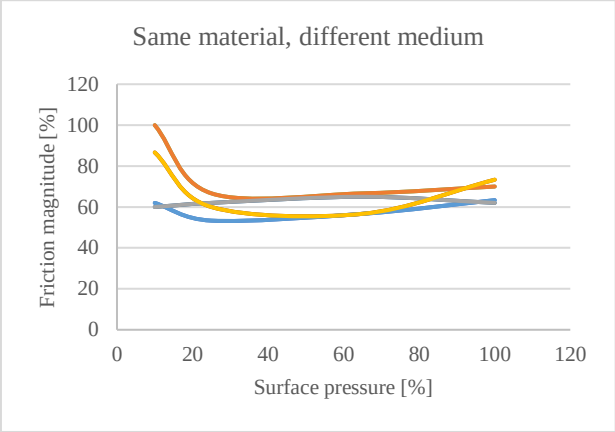

Fig. 3. Friction vs. surface pressure in different environments

Figure 4 shows friction magnitude for different materials in the same medium which the bearing assembly is placed in. It can be observed that there is quite a difference between bearing materials; counter-material being the same. The diagram is prepared for one operating point (surface pressure). For different surface pressures, the relative difference in friction between the same materials may be completely different.

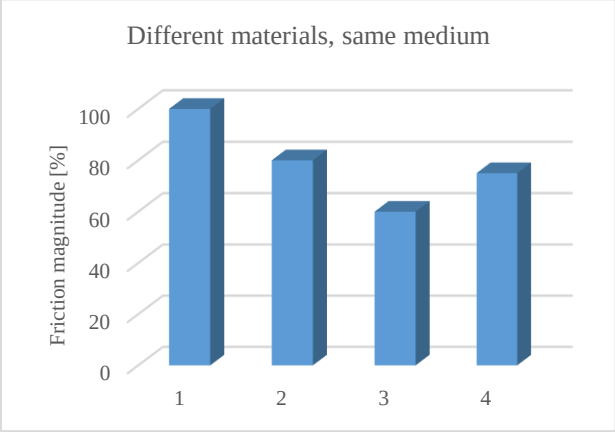

Fig. 4. Friction vs. bearing material

4. Sealing

In ecological runners sealing is quite an important piece of the puzzle. Seals isolate runner hub from the river water. -They must be resistant to any fluid (environment) they are exposed to.

Seals are widely used in all sorts of applications and are one of most widely used machine elements, it is expected that manufacturers have their own reliable results on resistance to all kinds of chemicals.

For correct selection of sealing and prediction of the sealing lifetime of the main runner blade seals it is important to take additional consideration into account. Due to dimensional tolerances in the bearings of the mechanism, the main runner blade seal and runner blade trunnion are never coaxial. Secondly, bearings, especially synthetic composite ones, have very low Young modulus what causes even more eccentricity. Furthermore, over the years of operation wear of seals and bearings is present.

5. Fatigue

It is usually prescribed in the technical specification provided by the Customer what is expected as service lifetime of the equipment. It is well known fact that endurance limit of steel, especially stainless steel can be significantly lower in some environments compared to one in the air. Carbon steel is usually protected by layers of paint, however stainless steel is not. In Litostroj Power, calculation of expected lifetime for critical mechanism components is performed for all designed runners and designs adapted accordingly if needed.

Primary grid frequency control supported by generating units is, according to EU regulation 2016/631, required for all new and upgraded/refurbished units. Due to frequent grid frequency oscillation out of ±20mHz dead band zone from the grid nominal frequency of 50Hz, the governor power corrections are required practically on the minute basis. Number of runner movements and thus induced load cycles in such operation is dramatically increased comparing the stationary operation with constant governing references. Increased number of load cycles in runner mechanisms affects steel structure, bearings and seals. In quite a few cases, we have seen the customers were not aware of loading collectives due to participation in primary grid frequency regulation. New governing requirements showed to be an important aspect to be considered during the Kaplan runner mechanism design.

6. Dry versus wet ecological runner hub - Pros and cons

Different runner environment solutions have been compared to each other for various effects/requirements. Comparison is presented in Table 1.

Table 1: Comparison of various effects/requirements in different environment

	Wet – water filled	Dry	Oil
Corrosion protection	Additive (corrosion inhibitor)	Mitigated with design	No protection needed
Galvanic corrosion	Inhibitor needed	Mitigated with design	Not present
Crevice corrosion	Inhibitor needed	Mitigated with design	Not present
Mechanism bearings	Influenced by additives	/	May be influenced by oil
Sealing	Attention for sealing selection needed in combination with applied additive and chosen bearing material	/	Attention for sealing selection needed in combination with oil type and chosen bearing material
Monitoring	Fluid level monitoring possible	Fluid presence monitoring possible	Water in oil monitoring possible
Maintenance of runner hub contents	Replacing complete additive mixture	Release condensed water if present	Replacing entire quantity of oil
Fatigue and Lifetime expectancy	Worst	Better	Best

7. Future developments

Enlarging the knowledge database, introducing new materials and educating junior design engineers is being performed and the process will continue.

Genetic algorithms are being implemented into runner design to optimize runner mechanism geometry. This approach leads to minimizing friction forces and thus prolong service lifetime of bearings and seals. Results of optimized runner mechanism can be used also in optimizing of oil regulating system.

8. Conclusion

Among several challenges that were met during our journey from the design of first oil free runner up until now, as we are developing new generation of ecological runners, our view on corrosion, friction, wear, environment in which material operates as well as correlation between them, widened to the extent that Litostroj Power is ready to offer and design excellent runner mechanisms.

It showed to be of extreme importance to conduct thorough analysis of materials used in the runner hub and runner mechanisms in combination with applied corrosion protection environment. We showed that sealing and bearing properties strongly depend on the corrosion protection environment applied and that in many cases material behavior data from catalogues are not sufficient for proper design.

In recent years, Litostroj Power initiated a cooperation with several different manufacturers of materials and components that are used within the runner hub with the goal to obtain knowledge regarding how the installed components behave under different operational and environmental conditions. In addition to such cooperation, material samples were gathered from manufacturers to conduct independent laboratory research and testing.

With right design approaches, the corrosion issues can be successfully mitigated both in water filled as well as dry runner hubs, making both options possible for site installations.

Finally yet importantly, within Litostroj Power we encourage the discussions of the design teams internally or with customers about research and ways of implementation of acquired knowledge into the ecological runner design.