Alstom Francis Turbine Ring Gates: from Retrofitting to Commissioning

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Abstract:

The Ring Gate synchronisation system developed by Alstom is new and patented. It uses hydraulic cylinders connected in pairs by a serial connection. The new hydraulic synchronisation system, when compared to the previous mechanical synchronisation system, has several advantages. It is a compact design; it reduces the number of mechanical components as well as maintenance costs. The new system maintains the Ring Gates robustness.

The new approach is an evolution from mechanical to hydraulic synchronization assisted by electronic control. The new synchronization system eliminates several mechanical components that used to add wear and friction and which are usually difficult to adjust during maintenance. Tension chains and sprockets and associated controls are eliminated.

Through the position sensors, the redundancy of the ring gate synchronization system makes it predictable and reliable. The electronic control compensates for any variation in operation, for example a leak in the hydraulic system. An emergency closing is possible without the electronic control system due to the stiffness of hydraulic serial connection in the hydraulic cylinder pairs. The Ring Gate can work safely against uneven loads and frictions.

The development will be reviewed and its application discussed through commissioning results.

1. Introduction

A ring gate is made up of a cylindrical shaped steel plate located between the stay ring and the wicket gates (figure 1). In normal operation, the ring gate is not used to control the water flow. It opens before the turbine start-up with the wicket gates still in closed position and it closes only after the wicket gates are completely closed. Under exceptional emergency conditions, the ring gate is designed to allow closing against the turbine full discharge. The primary purpose of the ring gate is to isolate the distributor from the upstream water pressure, eliminating leakages through the wicket gates during turbine shut down. When in open position, the ring gate does not interfere in the flow path, which is an advantage over a conventional inlet valve that has head losses.
Ring gates were originally operated with six hydraulic cylinders or so-called servomotors. Each servomotor is directly attached to the ring gate at the lower end and to a special screw at the upper end. The screw transforms the servomotor linear motion into a rotation, allowing linking of all six servomotors together with the standard synchronization system made of chains and sprockets, (fig. 2). The synchronization system moves up and down the servomotors at the same time and keeps the ring gate horizontal.

The ring gate system consists of the gate body, the linear or rotary operators, the synchronization mechanism and the hydraulic and electronic control systems. See reference 1 for more details.

The first ring gate concept has been patented by our company in 1947 and more than 50 units are now in operation worldwide. In 1974, the ring gate concept was chosen to equip 16 large Francis Turbines of 333 MW under 137 m head. Back then, these ring gates were the world’s largest with an outer diameter of more than 7.5 m. Eight of these ring gates are originally described in reference 4. In 2012, a contract was awarded for the turbine refurbishment, including the ring gate.

The objectives for the ring gate’s refurbishment are: (1) offer a solution with minimum maintenance, (2) keep the ring gate horizontal during normal operations, (3) improve the reliability of the ring gate over its full stroke for normal and emergency operations, (4) limit the dashpot pressure during emergency closure and under the maximum flow condition of the turbine, (5) ensure that stresses and deformations are acceptable even for the highly improbable case of jamming.

To achieve these goals, a new synchronisation system has been developed, eliminating chains, sprockets, controls and associated equipment. This new concept was developed for new units and has now been successfully adapted and implemented on a refurbished ring gate. As it will be detailed, various modifications were also done on the existing ring gate to preserve and to improve its reliability.

2. Original Arrangement

The ring gate refurbished in 2013-2014 is not originally designed and supplied by our company. For economic reasons, the ring gate itself has been re-used, but the original control mechanisms with the hydraulic operators, along with the mechanical chains and sprocket, were all removed and replaced by a new synchronisation system. For convenience, we provide some details in the following section.
2.1. **Mechanical synchronization system**

We can see a conventional synchronization system on Figure 2, with two (yellow) hydraulic operators and guards (blue) for the chains of the synchronization system at the top. The operator’s stems are linked with a continuous chain loop at the top and they are guided through the head cover where they are rigidly attached to the top of the ring gate. The hydraulic operators are fed with pressured oil supplied by an independent pressure system.

If the ring gate is not level or if the speed of a hydraulic operator leads or lags, the tension in the synchronizing chains is affected and triggers a limit switch to stop the operation.

2.2. **Existing System at Power Plant, before refurbishment**

The ring gate body with its upper water seal and guiding segments on the stay ring were preserved. Necessary modifications were implemented as needed. The hydraulic power unit (HPU) with 4400 gallons at 900 psi air over oil accumulator charged by a screw pump was preserved. This system used to feed the six rotary motors and it can deliver much more oil than now necessary for the six linear servomotors used to control the gate. The original ring gate motors and control system were discarded.

2.3. **Feedback of Experience**

There was an important concern of vibration. Intermittently, the ring gate could not properly sit on the bottom seal, leading to leaks that caused important gate vibrations. Over the years, maintenance personnel have developed an adjustment procedure to improve the condition.

The lifting stems of the refurbished ring gates were also known to be vulnerable. Due to ring gate’s displacements and deformations in operation, the junction where the stem is attached to the gate can be exposed to important bending forces. For these gates, the stems are also exposed to important traction forces due to a down pull from the water flow. To prevent relevant bending and fatigue on the stems, two design changes are required. For bending, stem should be designed such that a cantilever length has to be increased and that an attachment of stem and gate body, for fatigue, has to be preloaded appropriately.

The down pull on the gate is influenced by its lower edge profile. This profile matches both the bottom ring profile to seal and the head cover and stay ring shape to suite the hydraulic profile. A different approach to control the down pull is normally possible at design stage. As the ring gate was preserved, it was no longer possible to considerably improve this point.

Having already refurbished ring gates with the same design between 2003 and 2008, these difficulties and associated problems were anticipated. The commitment was not only to implement a new synchronization system but also to solve these issues.
3. The Re-Design

This section will detail the approach for the refurbishment and mechanical solution involved. As it is a refurbishment, it is necessary to find a way to accommodate the existing parts and the new design.

3.1. Lifting stem

The weakest point was the connection between the lifting stem and the gate body. This rigid connection is sensitive to high bending moments induced when the ring gate moves radially within its guiding segments installed on the stay-vanes outlet. A flexible lifting stem was designed which combines a tube and a rod freely passing in its center. The rod is attached to the gate body at its lower end, and to the piston at the top. This mechanical assembly is no longer sensitive to bending. The tube allows to pre-load the rod axially (see figure 3) and to seal both the water into the turbine, and the oil into the servomotor. The axial pre-load is usually done with a special wrench designed for this purpose, but it is now done with a "Supernut". This compact multi-jack bolt tensioner can achieve high preload and requires only a limited space and a standard hand tool to be loaded. This is compatible with the limited space available around the servomotors into the turbine pit and induces no torsional stress in the rod. It offers also more precision for the pre-load and is easier to use at assembly and if necessary, for maintenance purposes.

As already explained in the context of the refurbishment, it is necessary to accept the existing lower gate profile and associated down pull. The dimensions and material selected for the design of the new lifting stem took into consideration the existing down pull to make sure the stress level will always remain acceptable.

3.2. Fabrication

For transportation reasons, the two ring gate’s halves had to be separated at site. Special attention is necessary during the entire refurbishment to make sure the coupling faces of the gate’s halves will not be altered during transportation, during work in the shop, or during reassembly at site. A spider was designed to preserve the geometry of the gate’s halves to prevent deformation.

Although the gate body is made from a 127 mm thick plate (5 inches thick), with such a large diameter it is still considered as a thin and flexible ring. When free on a machine or after machining and also after assembly at site, the gate does not necessarily remain round. For this reason, for the design of a new ring gate, the lifting stem’s coupling holes were drilled at site, using the head cover as a template. For a refurbished gate it is a problem to align the existing holes. Using a practical approach, the head cover coupling holes were enlarged in the workshop, to accommodate the potential eccentricity of the existing gate’s coupling holes. The solution eliminates the need for machining these coupling holes at site which also positively reduces site schedule and costs associated. This also eliminates the works of assembling the head cover and ring gate together for line boring of these holes in the shop or at site. As a result, these two large components could be refurbished without scheduling dependency and were ready early for shipping and site assembly.
3.3. **Stem Seal**

Costs and site erection time can be reduced if the head cover’s coupling holes for the stems are enlarged, but this raises an issue with water seal. Since the coupling holes are through the head cover, they reach the river water and this imposes to find a proper solution to seal the area. The solution has been to add a free or floating sealing sleeve into the head cover. As shown on figure 4, this sleeve has a smaller diameter than the hole into the head cover, allowing some flexibility for its position or adjustment. The tube of the lifting stem (see section 4.1) is centered with the coupling hole of the ring gate and also with the bushing mounted into the servomotor’s base, and both holes are not necessarily centered. The sleeve is free to move radially to accommodate eccentricity.

3.4. **Gate Seal**

The existing lower seal assembly imposed a very tight levelness gate seal adjustment. The original allowable seal compression was less than 1 mm (0.040 inch) over the entire diameter of the ring gate of more than 7.5 meters (25 feet) in diameter. When the ring gate is closed, its lower sealing face doesn’t remain perfectly horizontal and as for the bottom ring, its flatness is not totally perfect. Because of these three factors, it was possible to exceed the allowable seal compression on one side while not sealing or having clearances on the other side. It is believed that it can explain the important vibrations observed on these gates.

The objective is to make the range of seal deformation large enough to compensate for these geometrical and functional tolerances. New seal shapes have been investigated by numerical analysis and experiments and it was found possible to increase seal deformation. In the same time, the seal retainer is changed to further improve its flexibility and to ease its maintenance.

4. **Design of a new synchronization system**

The purpose of the synchronization system is to keep the ring gate levelness in operation, this means moving all cylinders simultaneously as one unit.

4.1. **Selection of a new solution**

One important parameter for the new synchronization system and the gate control system development is that the ring gate must be capable to close under emergency condition, even if the electronic system should fail. Therefore, a system based only on an electronic position regulation is not applicable. A system based on mechanical synchronization requires a lot of maintenance, and reducing maintenance is required. As a result, these two solutions are not considered.
The only reasonable choice left is to use a volumetric system, which means fixing the distance between cylinders by the enclosed volume of hydraulic fluid. The serial connection between cylinders used for the Ahai project (China) is patented and applied in other projects.

4.2. Basic Concept for the new Ring Gate Synchronization system

The new solution uses fluid transfer and ring gate rigidity to synchronize the ring gate operation. To illustrate the concept, refer to figure 5 below.

There are six equally spaced linear servomotors for this concept (see figure 6). It consists to have equal effective area for the upper chamber of cylinder number one (in yellow in the diagram below) and for the lower chamber of the cylinder 2 (also in yellow). An orifice plate located at the outlet of cylinder 1 controls the operating speed. When cylinder 2 moves down, the volume of oil leaving this servomotor is transferred to cylinder 1. Since the areas of both cylinders are equal, the piston displacements must be the same. Synchronization is then achieved. This implies two servomotors of different sizes. There are three large servomotors linked with three smaller servomotors for a total of six servomotors or three pairs of servomotors. For each pair, the larger and smaller cylinders are located 180° apart on the ring gate, as illustrated on figure 6.

The position of each servomotor is recorded with two sensors to increase security and redundancy. If a pair of cylinders is above or below the other two pairs, to improve the ring gate horizontality, a proportional valve rebalances the gate in order to have all three servomotors pairs at the same position and speed. Pressure is also monitored in each servomotor to detect abnormal conditions. Electronic synchronization is only done in normal operation, or in manual mode; for emergency closing or flow cut-off, the electronic control system is not used, and less precision is acceptable in this situation. The synchronization between each pair of cylinders is mostly achieved by the ring gate’s rigidity and the orifices.

4.3. Elaboration of the new solution

The development of the new concept and its validation has been done in four main phases. First, engineering studies and analysis were done and numerical simulations and analysis were performed, to validate the concept. Second, a 2 meter diameter ring gate model was designed and fabricated and tested in the workshop. A factory acceptance test in China was performed for the Ahai project with the actual ring gate and servomotors. Lastly, real-time simulations were performed to validate the design of the electronic controller. These test proved to be successful and the ring gate was later installed in China. It is now in commercial operation. The Ahai project is noteworthy as it is the
heaviest ring gate in the world, with a diameter of 10m (almost 33 feet) and a stroke of 2.5m (about 8 feet).

The subject of the electronic controller will be discussed in a future paper, but the electronic control can be achieved by an industrial PLC or by the Alstom T.SLG dedicated controller.

4.4. **Ring Gate Finite Element Analysis**

A brief discussion is presented about the validations done by numerical calculations during phase one for the refurbishment, including some data collected during commissioning of the refurbished ring gate.

For the ring gate to be refurbished, the synchronization concept was validated with the help of finite element analysis (FEA). ANSYS, a general-purpose finite element program, was used to assess how the combination of hydraulic compressibility and mechanical structure stiffness affects the synchronization of the gate operating system.

The ring gate, lifting stems, inner and outer radial guiding segments and rigidity of synchronizing system were included in the model. Static stresses were also studied under many conditions like the free-state, flow cut-off, one pair of cylinders out of operation, unbalanced hydraulic loads and others.

The stress analysis was done with respect to ASME code, Section VIII, Division 2. All stress levels were acceptable compared to the threshold.

![Ring Gate FEA under obstacle condition.](image)

**Figure 7: Ring Gate FEA under obstacle condition.**

4.5. **Prototype testing of the refurbished ring gate**
After the refurbishment and the installation were completed, multiple tests were done while in dry condition in order to validate the basic design. During these test, many parameters were tested, mainly:

- Detection of an obstacle
- Bulk modulus used for leak calculation

During these tests, the gate remained horizontal and behaved as expected. The largest error observed was when steel plates of different thickness were placed on the bottom ring in order to simulate an obstacle preventing the ring gate from closing completely (see figure 8). This test proved that the system is able to detect an obstacle and freeze the gate in a stabilized position until the maintenance crew could remove the obstacle.

One important parameter for the hydraulic rigidity is the Bulk Modulus, which is equivalent to the Young Modulus for metal solid. However, this parameter is affected significantly by dissolved air, which makes it difficult to estimate a proper value for finite elements calculation. For reference, calculations usually use a value of about 1 GPa, but it could be from 0.7 to 1.5 GPa.

The bulk modulus is defined by equation below, where $\beta$ is the Bulk Modulus, $V$ is the initial volume of oil contained in the piping, $\Delta P$ is the difference of pressure between two stages and $\Delta V$ is the difference of oil volume in the piping for the corresponding pressure difference.

$$\beta = \frac{V \Delta P}{\Delta V}$$

During the commissioning, the parameter was validated by removing or reducing oil volume. All volumes and pressures were recorded on 3 pairs of servomotors.

Results indicated Bulk modulus of 1.1 GPa is a correct value for our application (light oil ISO 46). Moreover, the Bulk modulus variation between the three pairs is about 2%.

Other tests performed during the dry test permitted to test accidental case, such as software malfunctioning and operation with one pair of servomotors out of function. All these tests were completed without any defaults and the system could then be tested for one of the most extreme case, which is the full flow cut-off.

The full flow cut-off has been done by locking the wicket gate at full open position and then shut down the ring gate without any control. To prevent the unit to runaway condition, the generator is connected onto the grid at synchronous speed (therefore going into motorization).

For precaution, the testing was done in 5 steps with 5 wicket gate openings: 14% (corresponding to speed no load), 40%, 60%, 80% and 100%.

Important parameters were recorded during these tests in order to be sure nothing unusual is happening and also to permit analysis thereafter. These parameters include the pressure in each servomotor chamber, the servomotor position, the spiral case pressure, etc.

Table 1 shows the maximum error in levelness obtained during the various flow cut-off. It shall be noted that the maximum values usually occurred at the beginning of the closing, probably caused by the difference in reaction time between the different pair. Once the flow cut-off is engaged, the error reduces and then stabilized at much lower values (closer to 2-3 mm). It is important to note...
because it shows that the system is intrinsically stable and is therefore able to restore the flatness of the ring gate.

| Wicket gate | LEVELNESS |
|-------------|-----------|
| Opening     | (mm)      |
| SNL         | 3.5       |
| 40%         | 4.0       |
| 60%         | 3.8       |
| 80%         | 5.0       |
| 100%        | 6.5       |

Table 1: Gate levelness at emergency shut off tests

The servomotor pressure recorded during the tests also permitted to validate the load encountered by the ring gate and the distribution between them. As shown on figure 10, the load distribution between the master cylinders is relatively equal; therefore no servomotor is more solicited than another one, which prevents uneven wear between the pair of servomotor.

The servomotors were designed to withstand a pressure of 24 000 kPa (3480 psi). As shown on figure 9, a maximum pressure of about 16 400 kPa (2 380 psi) was encountered. This pressure was caused by the orifice restriction on flow and is due to the ‘GATE DOWN PULL’. The maximum down pull occurred during 60% cut off test and was of 1487 KN (167 tons) for a design value of 1962 KN (220 short tons). During 100% cut off test, it is interesting to note that the maximum down pull recorded was much less with 961 KN (108 short tons), and this occurred at around 5% of ring gate stroke.
During the flow cut off test, the closing time required by the customer is equal to 10 times the wicket gates time, which is 13.5 seconds. The recorded closing time was 229 seconds and found to be acceptable.

5. Conclusion

A ring gate is economical and useful equipment for a power plant. As it can be used to stop the unit under emergency conditions, its design must be reliable and robust. The synchronization system is a key element to allow the gate to remain level during closing. To be reliable, this system must not rely on electronic control. A new solution has been successfully developed and tested on some of the largest ring gates in the world and it was found satisfactory. Even under shut off and without electronic control the behavior of the gate was acceptable. This new solution eliminates many mechanical components associated with the conventional synchronization system, reducing maintenance costs and operates with less oil than the previous systems. This solution is now available both for new or refurbished ring gates.

The refurbishment is now completed and the ring gate has been successfully commissioned in March 2014. The problems associated with the existing synchronization system plus the new requirements were solved satisfactorily and the ring gate accepted for commercial operation.

References:

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