TURBINE DESIGN NEED OF THE HOUR

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Abstract

Starting with the success of bulk tendering projects NTPC has installed a new fleet of supercritical and ultra-supercritical steam turbines. The fleet covers a variety of technology covering almost all the gamut of turbine OEMS worldwide. This has ensured adoption of state-of the art technology to meet the present day demand from our end customers. Justifying the phrase "*necessity is the mother of all inventions*", lot of changes have been made in the equipment design as well as in the system design to make the plant more suitable to take care of transients. Continuous endeavor is also made to make the system more and more suitable to meet the demand. This paper aims at listing down the features and their advantages and the flexibility offered by the specific feature to the operating staff.

1.0 Flexible operation and its demand from the plant

Ideal power plant is a plant which responds to the demand of the grid instantaneously and infinite number of times without compromising the efficiency and life of the equipment's. Unfortunately such ideal plants are not in existence and every system has its own inertia, finite life and operates with deteriorated efficiency when it is operated away from its design point. Among all types of power plants coal based thermal power plants (lest nuclear power plants) has highest response time as it possesses lot of mechanical and thermal inertia in it. Endeavor is always made by all OEMs and utilities to reduce this inertia and reduce the response time. There are many yard sticks to measure the plants capability for flexible operation. Some of the important parameters are as listed below. We will discuss the features of our fleet which some how or the other tries to address the requirement. The some of the unique features may be specific to some OEMS having design patents and may not be available in the machines of other OEMS. Same purpose could also be achieved by different design features by different OEMs.

Important yardsticks of flexible operation

(a) Ramp rate (both for load up and down)
(b) Minimum stable load
(c) Lower start up time (cold, warm and hot)
(d) Capable of higher number of start ups.
(e) Part load efficiency
(f) Above flexibility with minimum consumption of life

2.0 Design features and their effect

Some of the design features described below are specific to particular OEMs and hence all the features may not be present in all units. Some features may be available in some turbines where other features will be available in other turbines. Different OEMs may incorporate different features to meet same requirement. Some of the features are specified by NTPC and hence shall be common to all units.

2.1 Axially split barrel type HPT outer casing (curtesy Siemens/ BHEL)

The HP turbine is designed as double shell casing with vertically split guide blade carrier and axially split barrel type outer casing. The barrel-type construction enables almost complete rotational symmetry and large asymmetrical deformation and thermal stresses avoided, even with high steam parameter. The Rotor consists of mono-block forging with integrally forged coupling flanges. Due to the barrel outer casing design the thickness of the inner casing can be optimised and the differential temperature across the inner casing also minimised. This reduces the stress levels and also variation of stress during transients are minimised. It helps in achieving higher ramp rates as well as reduced start up time.

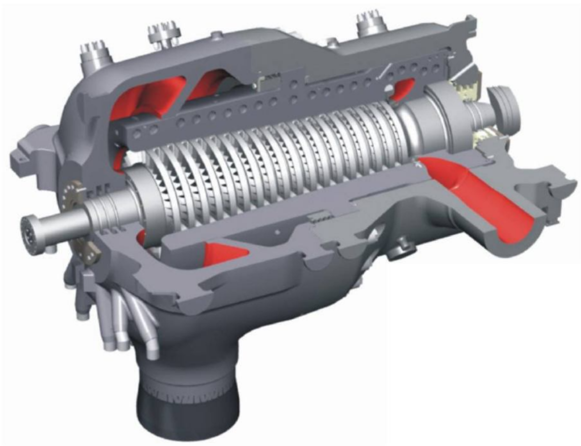

Fig:- 1 Axially spilt barrel casing (curtesy Siemens/ BHEL)

2.2 Shrink ring design for inner casing without flanges

The turbine is of double shell design with an outer and an inner casing. The parting plane of the outer casing is horizontal at the level of the rotor axis. The outer casing is assembled by means of hydraulically tightened expansion bolts. The inner casing is mainly assembled by means of number of **Shrink Rings** instead of flanges and bolts. Thick flanges in the inner casing as well as the tightening bolts are avoided. The Shrink ring design allows for a rotationally symmetric casing resulting in reduced distortions while clearances are maintained during operation- providing sustained higher efficiency. It offers a compact design with smaller wall thickness for flexible load cycling and faster start up time.

Since the distortions are less, the design ensures leak-free operation for a longer period under steady state as well as transient operating conditions. Due to axisymmetric design the stress levels are very low even with higher temperature gradients across the casing. Hydraulic bolts along with shrink ring design reduces the assembly / disassembly time and hence overhauling duration. Overall weight of the turbine is also reduced due to avoidance of flanges and bolts. The design helps in rapid start up / shut down, two shifting operation and also exhibits excellent behavior during cycling loadings.

Fig: 2 Shrink ring HP turbine inner casing (Curtesy GE)

2.3 Welded Rotor design

The rotor is of **welded type** with integral coupling halves. This design allows selection of appropriate forging material based on temperature level at each section. Materials having higher creep / yield strength at higher temperature are susceptible to brittle failure at lower temperatures.

This design has the flexibility to select high ductile material at lower temperature zones. Because of smaller forgings number of suppliers are available and the lead time is also low. Further due to smaller size forgings the quality can be more accurately controlled and the defects can be detected / rectified easily. The weight of the rotors are less (hollow spaces in between) as compared to solid mono block forged rotors. It results in stress reduction during thermal transients for faster and frequent load cycling.

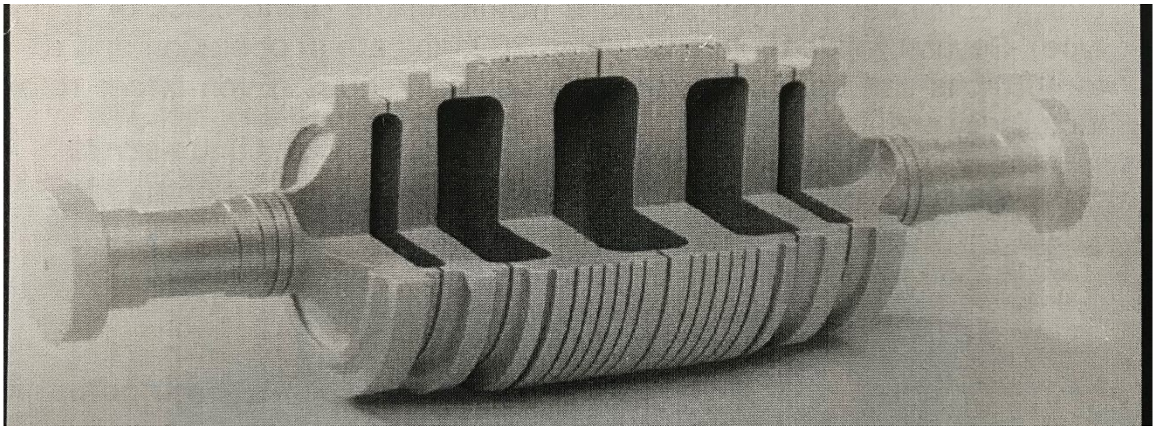

Fig: 3 Welded rotor design (Curtesy GE)

2.4 Internal cooling of outer casing and balancing piston

HP turbine inlet section is the point where the turbine experiences highest temperature as well as highest pressure. In order to accommodate the high pressure and high temperature the components are bound to be very thick. During transients the temperature as well as the pressure at this location also changes very fast inducing higher thermal as well as mechanical stresses. The situation further aggravates due to thicker components. Higher the thickness higher the thermal stresses inducing higher fatigue loading. OEMs always thrive to reduce the thickness of the casings (both inner as well as outer casing) be it by introducing double casing design or shrink ring design / barrel outer casing eliminating flanges etc. In this design lower temperature and lower pressure steam is extracted from the HP turbine intermediates stage through the annular space between inner casing and outer casing and introduced to the balancing piston. This steam is divided into two parts. First part flows toward the shaft glands and the remaining steam towards mixing chamber where it get mixed with the leak off after the diagonal stage and flows back to further downstream stages.

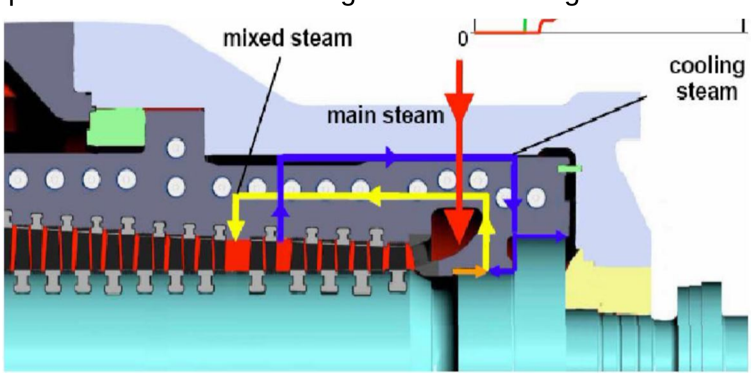

Fig4:- HPT internal cooling arrangement (Curtesy- Siemens/ BHEL ltd.)

This arrangement serves two purposes (1) it cools the outer casing thereby not exposing the outer casing to higher temperature of Main Steam. This reduces the thickness of the outer casing as well as the stress levels. Further the turbine glands are also exposed to lower pressure and temperature. This feature can accommodate higher ramp rates as well as lowers the startup time.

2.6 Concept of rotor and blade cooling / Heat shield at the highest temperature location

It shields the highly stressed components and thereby exposing the metal to much lower temperature than the expected temperature. Increases fatigue and creep life of the highly stressed components. Normally at the inlet section of IPT as it is the highest temperature location. Due to this arrangement the rotor is exposed to much lower temperature and hence have lower creep and Low Cycle fatigue stresses. Some design envisages cooling the inlet stages of IP turbine stationary and rotating blades by introduction of steam of lower temperature through drilled holes in the blades. This way thermal stress in the highly stressed component like rotor is reduced facilitating better transient behavior.

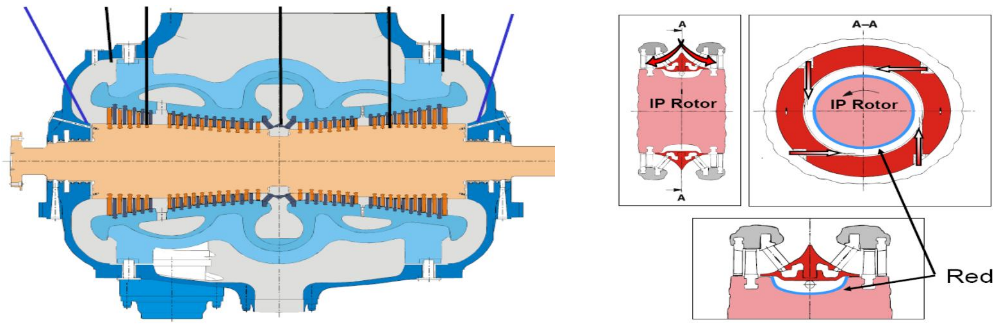

Fig: 5 Thermal shield for IP turbine (Curtesy Siemens / BHEL)

2.7 Single bearing design with sliding casing / Bearing pedestal design

2.7.1 Single bearing concept

Only one bearing is envisaged between two turbine cylinders even between LP turbine and Generator. This design enables more accurate prediction of bearing loads as compared to individual bearing design due to manufacturing and erection reasons. Due to determined bearing loading / stiffness the critical speeds can also be predicted more accurately. Accurate prediction of bearing loading & critical speed reduces the shaft vibration levels. This design reduces the lube oil consumption as well as bearing losses. Overall length of the shaft line also gets reduced.

2.7.2 Sliding bearing pedestal / casing

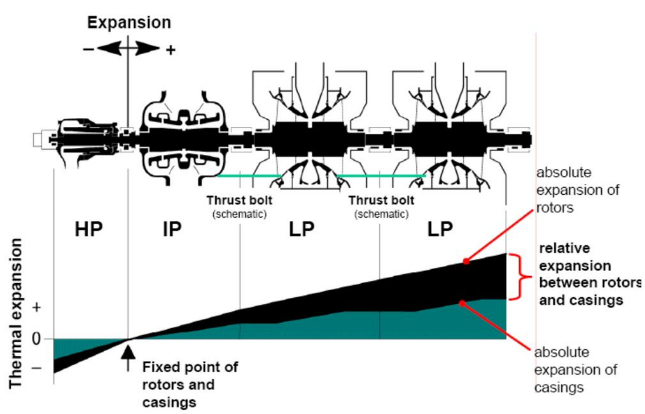

Fig:6 Expansion diagram with self-compensating nature

The bulk material temperature for the turbine shaft and the turbine casing are always different. The difference is more during startup / shut down and minimum during steady state operation. Higher the differential expansion higher the chance of interference between static and rotating parts. The thermal expansion of the turbine shafts from HP to LP is bound to be added up as the shafts are directly coupled with each other. However the expansion of the casings only start from the respective fixed points. If individual shafts have their own fixed point (as in case of older designs) then the casing expansions are not integrated with each other and the differential expansion is more at the farthest point of absolute shaft fixed point (i.e. thrust bearing). Sliding bearing pedestal / casing design has only one absolute fixed point for the casings also wrt thermal expansion point of view. This gives rise to self-compensating nature of the turbine train.

2.8 Abradable seal design

It is the endeavor of all OEMs to reduce the clearance between static and rotating components. Higher the clearances higher the losses results into lower efficiency. However lower the clearances higher the chances of interference between static and rotating components specifically during transient conditions like startup, shutdown & load changes etc. and hence reduced long term sustained efficiency. The relative position of the shaft and the casings are different during steady state condition as compared to that of during startup / shutdown. This fact is exploited by use of softer coating over the shaft (abradable seals) in the seal area and closing down the clearances. During startup / shut down when the differential expansions are higher the gaps between static and rotating components close down and even the seals are allowed to rub the softer coating increasing the gap. As the units moves towards steady state condition the relating position of the shaft and casings changes and the seals faces the unrubbed portion of the coating where the clearances are still low (un-rubbed). This increases the steady state efficiency maintaining the reliability during transients.

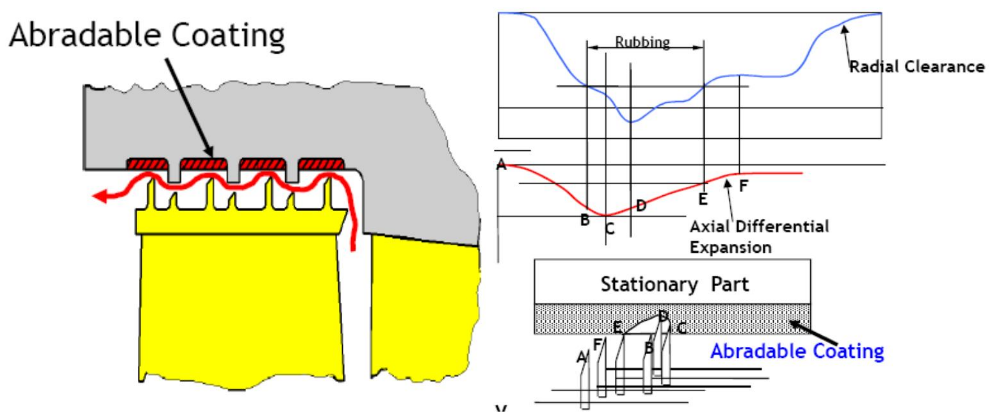

Fig: 7 Abradable seals (curtesy:- Toshiba)

2.9 Shifting the design point

The thermal cycle and its components are optimized for a particular condition. This condition is called the design point and Operation at this condition results in maximum efficiency. Any deviation / departure from this point results into off design operating condition and obviously results in deteriorated efficiency. Higher the deviation / departure lower the efficiency. Hence all endeavor should be made for operating the plant as close as possible to the design point. While designing the power plant the expected operating regime is kept in mind so that the design point should match with the expected most frequent (maximum number of hours) operating point in the life time of the plant. Till about 2015 plants were operating with very high PLF (~90%) i.e. most of the time the units were operating very near to the rated load and sometimes even at 105% of the rated load (VWO condition). Hence all the plants are optimized for 100% TMCR condition having highest efficiency at 100% TMCR load. Off late due to the advent of renewable energy the plant are operating at lower PLF (~60%) and in future it is expected that the PLF will further go down and the thermal plants are expected to run at part load for most of the time. Hence it is necessary that the plants be optimized at part load condition rather than at rated load so as to derive most efficient operation. Keeping above objective in view certain changes have been done in the specification stage itself.

2.9.1 Provision of over load valve

The plants are designed for a continuous unrestricted capacity of 105% of the rated load. This is necessary to meet the grid demand / Indian grid code. Hence all the turbine components including MS control valves possess this capability irrespective of its operating point. During lower load operation the plant is envisaged to operate sliding pressure mode. However operating in pure sliding pressure operation reduces the instantaneous load peaking capability of the unit as there is no thermal reserve. Hence the units have to operate under modified sliding pressure operation with a throttle reserve of about 5%. Hence about 5% throttling takes place in the MS control valves. Throttling in the MSCV results in continuous loss in efficiency. Provision of overload valve (OLV) allows operation on the unit in pure sliding pressure mode of operation without compromising the load peaking capability. The OLV bypasses some initial stages of the HP turbine and the steam is admitted after say 4th stage. This increases the swallowing capacity of the turbine without increasing the inlet pressure (increasing the area of admission). The MSCV always operates full open and the peaking capability is realized by OLV. During operation of OLV the plant efficiency reduces but for a very short period of time allowing efficient operation during normal operation.

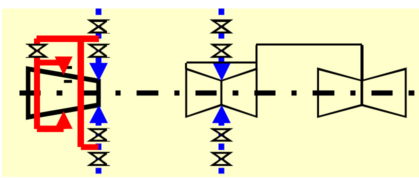

Fig: 8 Provision of Overload valve

2.9.2 Cycle optimization for partial load

Previously the plants were being optimized for near about full load condition and accordingly the heat rate guarantees were asked for at 100% TMCR and VWO (105% TMCR) condition. Bid evaluation factors are specified for the quoted heat rate by various vendors. Credit for better heat rate is given to the bidders based on this factor. During PG test if the contractor fails to meet the quoted guarantees then Liquidated Damages (LD) are deducted based on previously specified LD values. In order to get higher evaluation credit the OEMs optimize the cycle at near about 100% load condition. Off late the requirement for more efficient operation in partial load condition has arisen. Accordingly the guarantee point have now changed to 100% TMCR and 60% TMCR condition so as to encourage the bidders to optimize the cycle and the equipment's somewhere between 60 – 100% load. Instead of separate guarantees at different load points one single weighted average guarantee has been asked with 50% weightage for 60% load and 50% at 100% load condition.

2.10 Startup modes with the aid of TSE

During design all the designers apply factor of safety in the design. This factor is also known as factor of unknowns or uncertainty. Lesser the knowledge on the subject higher the factor of uncertainty to be applied to take care of unknowns. Higher the available information in terms of measurements, prediction tools this factor can be reduces and the capability of the equipment's / components can be exploited without the fear of failure. The Turbine Stress Evaluator plays a vital role during startup providing all information to the operator to control the startup process. This also protects the turbine from damage. In the initial generation turbines this tool was not available (some plants are still operating without TSE). The startups were governed by certain thumb rules / time dependent criteria specified by the turbine manufacturer. Obviously this method cannot exploit full capability of the machines. Subsequently the tool was developed and refinements were carried out as the technology matured. Following are the different stages of development of TSE giving more and more accurate prediction of life consumption.

Generation # I TSE:- The life consumption of critical turbine components were calculated based on number of startups and operating hours.

Generation # II TSE:- Startup mode were differentiated. Life consumption during Cold, warm and hot startups were differentiated. Similarly different modes of startup (slow, moderate & faster) were also envisaged so that the operator can decide for faster startups based on grid requirement. The information on life consumption is also made available.

Generation # III TSE:- This was based on actual stress measurement of critical components. This method provided more accurate predication of life consumption as it is based on measurement.

Generation # IV TSE:- Present day TSE also takes load changes into account while calculating the life consumption.

From the above developments it can be seen that more and more information is being made available to the operating staff during actual operation so that the capability of the plant can be utilized to the fullest.

3.0 Snapshot of yardsticks

Due to continuous upgradation process lot of improvements have been achieved in the performance parameters which will help in meeting the present day demand. Keeping the present day grid demand in view comparison of some of the yardsticks of flexible operation (older units vs present day units) has been compiled in the table below.

Parameters	**Older units**	**Present day units**
Primary mode of operation	Base load operation	Two shifting / Cyclic load operation
Total Number of startups in life time	Cold:- 150 Warm:- 450 Hot:-1400	Cold:- 150 Warm:- 1000 Hot:-4000
Startup time	Cold:-340 Warm:- 200 Hot:-90	Cold:- 126 Warm:- 60 Hot:- 20
Steady state Ramp rate	1% per minute	5% per minute

4.0 Conclusion

Design upgradation is a continuous process. The expectations of the end customers are also changing day by day. Even if the technology is matured it is necessary to make changes in the existing features to meet the present day requirement. Further market forces such as competition from peers also acts as catalyst for upgradation. Call of the present day in power sector is flexible operation of thermal units. Accordingly lot of modifications are done to make the unit more capable of flexible operation. The endeavor shall continue in future depending upon need / demand from the end users.

References

1. *Ministry of Power, Government of India website*
2. *Central Electricity website.*
3. *Technical presentations and O&M manual of various OEMs (Siemens, GE, Toshiba, LMZ etc.)*
4. *IEC 60045*