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**Research Paper**

# Determination of Flow Coefficient of a HP bypass Value using CFD

Dr. P.V.J Mohan Rao
*Professor & Head of Marine Engineering Department A.U College of Engineering (Autonomous) Andhra University, Visakhapatnam-530003 Andhra Pradesh, India.*

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***ABSTRACT:*** Modern power plants are designed for optimum performance in terms of efficiency and smaller down time. For optimal performance, these power plants require advanced design steam turbine bypass values and systems. A high quality bypass value and associated systems allows boilers and heat recovery steam generators to operate independently of the steam turbine. The key features of its performance are that it allows for quick start-up, recovery after a trip and avoids noise problems associated with accidental lifting of safety valves. Turbine bypass values operate under the most severe conditions, reducing pressure from nearly 200 bar t 40 bar and temperatures ranging from 500°C to 150°C in a very short time interval of less than a second. The HP bypass valve type considered in this work is a stream-conditioning valve for stream throttling with very high-pressure drop combined with in-body de-superheating through spray water injection. Proper design of a HP bypass valve requires a detailed understanding of the flow pattern inside the valve during all load conditions. Analysis of this flow pattern, including spray water atomization and evaporation is today possible with CFD package like CFX-5.7.1. The present work involves the complete simulation of the flow path tracing the flow of stream in a high pressure turbine bypass valve using single phase physics. The flow coefficient is calculated from the analysis and compared with experimental results. The effect of water injection is negligible in the calculation of flow co-efficient, so the problem can be considered as single phase. The non-dimensional flow coefficient calculated from the mass flow rate using the present CFD package agrees within 2% of the experimental result.

## I. INTRODUCTION

The major equipments in a thermal power station are boiler turbine generator and power transmission equipment. The superheated stream under high pressure from the boiler is supplied to the pressure cylinder of the stream turbine and expanded. After expansion, the low pressure exhaust steam is sent to the boiler and reheated. The reheated steam is again expanded in the medium pressure and the low-pressure cylinders of the turbine. With the expansion of the steam in the turbine the rotor of the turbine and generator which are mechanically coupled start rotating, generating electricity which is then transmitted to sub stations.

During Short trip outs, the supply of stream of turbine has to be totally cut off from the boiler. Once the short tripping is over, the turbine requires steam of a high temperature to reduce thermal shock as the temperature of the turbine parts is still high. If the low temperature steam from the boiler is admitted to the turbine, the turbine will be damaged due to the large temperature difference. This implies that the thermal power station has to remain idle until the turbine parts cool down to match the low temperature steam available from the boiler. This idle period will be quite high long since the cooling rate of turbine is very low. In order to avoid such idle time of thermal power station and to put back quickly the power station into the power grid, the high pressure and low pressure (HP and LP) bypass system is used in large thermal power stations of sizes 100 mw and above.

The Hp bypass value considered in this work is a stem-conditioning valve for steam throttling with very high-pressure drop combined with in-body de-superheating through spray water injection. The valve is specially designed for the cyclic operation of bypass systems. The value combines the function of pressure reduction and de-superheating. For pressure reduction a specially designed stem assembly plug is used. For de-superheating, spray water is injected through a large number of small injection nozzles directly into the zone of the highest turbulence of steam flow. This ensures a good atomization of the injected water, and due to the small droplet size, a very fast evaporation and an even temperature distribution at the valve outlet. The specially designed multi-function contoured cage breaks the steam jet into multiple small jets, ensuring noise attenuation. This cage also prevents water droplets from reaching the pressure boundary walls, thereby eliminating any chance of thermal shocks. Proper design of such an integrated injection requires a detailed understanding of the flow pattern inside the valve during all load conditions. Analysis of this flow pattern, including spray water atomization and evaporation is today possible with CFD package life cfx-5.7.1. The present work involves the complete simulation of the flow path tracing the flow of steam in a high pressure turbine bypass valve using single phase physics. The effect of the water injection is negligible in the calculation of flow co-efficient, so the problem can be considered a single phase. In this work the CFD package cfx-5.7.1 is used for flow simulation and visualization. The flow velocities at the tips, pressure distribution, temperature distribution and mass flow rate calculations are important parameters for the design of the valve. In the sections to follow, the procedures and other calculations are provided.

## II. CONTROL VOLUME FOR FLOW ANAYSIS

For any problem in computational fluid dynamics, the volume representing the flow characteristics is the control volume. It can also be termed as wetted volume or negative volume. This volume represents the actual path of flow in any system. Generation of control volume forms the first and foremost process of flow analysis. Control volume can be modeled within the flow analysis package itself, provided the package has inbuilt geometry modeling features. But generally the model becomes too complex and hence modeling needs to be done in a separate software package and can be imported as standard IGES file. As modeling the control volume of bypass valve, the geometry being complex, all the main components of bypass valve such as valve body, valve stem, valve seat, jet cage, pressure seal plug was modeled using commercially available modeling package “pro-e” and it is imported back to ICEM in an IGES format. Figures 1 and 2 shows the models drawn in Pro-E software. Since the model and the flow are symmetric about the middle plane, one half of the model is taken for the flow analysis.

**Grid Generation**

The grid generation is done using ICEM. After the initial result was obtained, mesh dependence study is done and the final meshing is created in hybrid mesh which is a combination of tetrahedral and hexahedral elements. The number of elements is around 600,000 (six hundred thousand). Figures 3 and 4 show the Grid Generation of the HP bypass Valve model. Figure 3 shows the overall mesh and figure 4 shows the zoomed view of mesh. The complexity in the mesh generation can be appreciated from figure 4.

**Flow Simulation Of The High Pressure Bypass Valve**

The analysis is performed with the following features. The analysis is run to give a steady state converged solution. The geometry being three dimensional in nature, three-D analysis was performed. The effect of the water injection is negligible in the calculation of flow co-efficient, so the problem can be considered as single phase. Steam is used as the fluid medium and compressible, turbulent non reacting thermal analysis is performed. Three different pressure conditions (150 bar, 162 bar and 200 bar) were considered for the analysis.

**Boundary Conditions**

Inlet pressure, temperature and outlet mass flow rate are given as boundary conditions and output pressure, temperature, velocity are obtained from CFX analysis results. Turbulence model chosen is the SST and k-ε models were used. Convergence criterion is taken as 1.0e-4. The solution converged after 150 iterations. The output pressure was used for calculation of flow coefficient.

As an example, for 150 bar inlet pressure condition, boundary conditions are as follows

**Steam inlet**

Inlet pressure = 150 bar, Inlet temp = 546°C, inlet flow rate = 67.5 kg/sec.

**Steam outlet**

Outlet temp = 500°C, Outlet mass flow rate = 67.5 kg/sec.

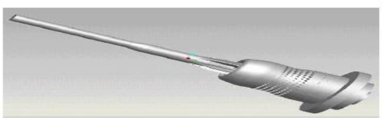

Fig 1: HP Valve Modeled In Pro-E

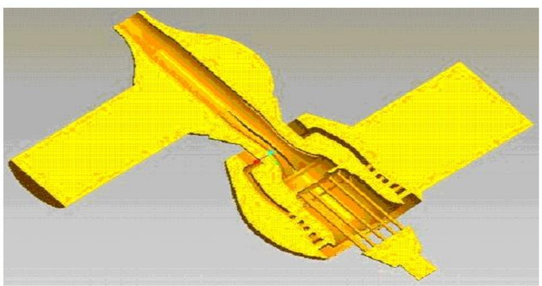

Fig 2: Control Volume of Flow Path for the Valve

# III. ANALYSIS, RESULTS & DISCUSSION

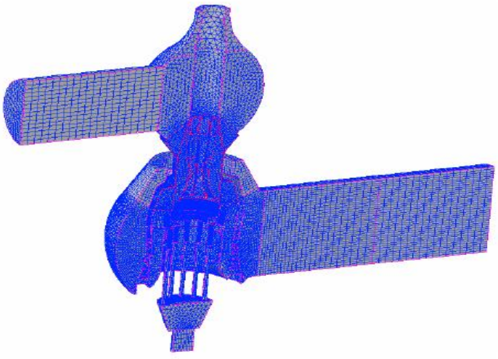

Fig 3: Grid Generation for Bypass Valve

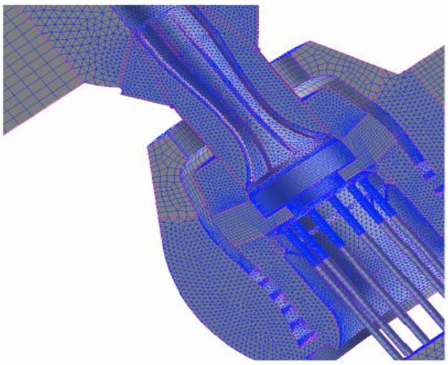

Fig 4. Zoomed View

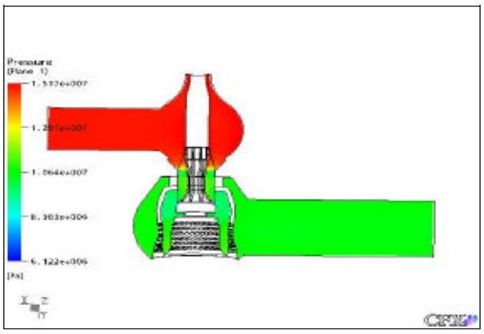

Fig 5: Pressure distribution

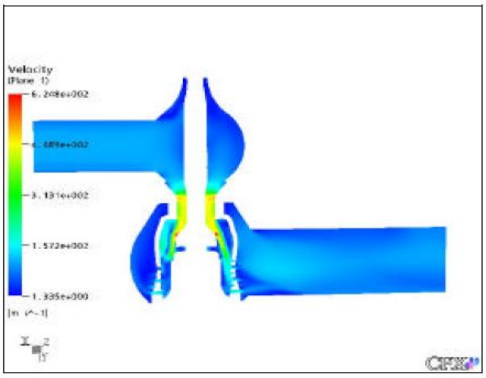

Fig 6: Velocity distribution

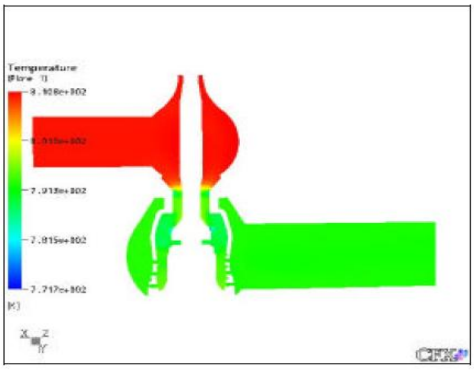

Fig 7: Temperature Distribution

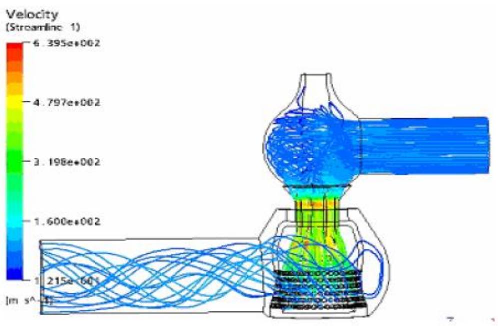


Fig 8: Flow Pathlines

The analysis was performed from three cases. The inlet stream pressure was varied from 150 bar to 200 bar. Representative solutions for pressure of 150 bar are only shown, Figures 5, 6, 7 show the pressure, velocity and temperature plots for the plane 1 of the bypass valve. Figure 8 shows the path lines. The exit temperature of steam is 540°C and it gives a sonic speed of 570m/s. The velocity at the tip outlet is around 640m/s and is supersonic with Mach No.1.12 which leads to shock. It is the supersonic speed that causes shock stresses in the bypass value. From the pressure data the flow coefficient (non-dimensional) is calculated and compared with the experimental value. The results agree very closely.

**FLOW COEFFICIENT Kv**

Flow coefficient is defined as the flow of water Q in m3/h measured at 4°C (Density = 1000kg/m³) which for a pressure loss of 1 bar, passes through the valve considered as entirely open. A value under dimensioned can generate a fall of pressure raised through of the device and can consequently damage the seat of the valve of erosion. Conversely a oversize control valve can involve an unstable operation of the installation.

For Each type of valve, the manufacturer indicates a limit differential pressure acceptable which depends on its diameter, of the method of construction, the power of the servo-motor, the temperature of the fluid, the leakage rate and of the maximum flow which crosses it.

$$Q = Kv.\sqrt{\frac{\Delta P}{\rho}}$$

Which Q = Actual flow rate in m³/h at the temperature x
r = Density of the water in kg/dm3 (Depends on the temperature)
DP = Pressure drop through the value in bar

The flow coefficients for different pressure drops is given in table below [9]

| | | | |
|---|---|---|---|
| Superheated steam | P2>P2/2 | $Kv = \frac{G}{31.7 \cdot \sqrt{\Delta P/V_2}}$ | • G = Mass flow rate (kg/h)<br>• DP =Pressure drop (bar)<br>• P1= Pressure upstream of the valve (absolute bar)<br>• P2 = Pressure downstream of the valve (absolute bar)<br>• v2 = Specific volume (m3/kg), under P2 and T1<br>• v = Specific volume (m3/kg), under P1/2 et T1<br>• T1 = Température en amont (K) |
| | P2<P1/2 | $Kv = \frac{G}{22.4 \cdot \sqrt{P1/V}}$ | |

The results obtained from the analysis are tabulated as follows: (for 150 bar)

| | *U/s pressure (bar)* | *D/s pressure (bar)* | *Superheat °C* | *Mass flow rate (kg/sec)* | *Flow coefficient non-dimensional* | *Error (%)* |
|---|---|---|---|---|---|---|
| *Outlet nozzle* | *150* | *105.780* | *351* | *67.5* | *249.8336* | *2* |
| *At seat* | *150* | *110* | *351* | *67.5* | *262.6759* | *2* |
| *Stem end* | *150* | *106.28* | *351* | *67.5* | *251.4863* | *2* |

## IV. CONCLUSIONS

The HP bypass valve type considered in this work was analyzed for the steam flow pattern inside the valve using CFX-5.7.1. The effect of water injection is negligible in the calculation of flow co-efficient, so the problem has been solved considering only a single phase. The pressures and temperatures at various locations along the valve are obtained using CFX5.1.7. The maximum velocity is found to be 624.8 m/s at the stem exit. The sonic speed at that location (at exit temperature of 540°C is about 570m/s). Thus a supersonic exit is occurring at the nozzle exit. This leads to shock loading on the valve. The exit velocity is supersonic and is believed to be responsible factor for the shock loading on the valve. Flow coefficient was calculated for the given HP bypass valve from cfd analysis, and the percentage of error was estimated to be 2& when compared with the actual test conditions.

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*Corresponding Author: Dr. P.V.J Mohan Rao