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Návrh spojení vysokotlaké a nízkotlaké turbíny

Turbomachinery 2015, Design of HP and LP turbine connection

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Abstract: This paper presents the design of high pressure and low pressure turbine connection in two stage turbocharger composition. The connection between both turbines was realized through the steel elbow, whose dimensions were limited by space requirements. Based on the space limits the shape of the elbow was changed. For the appropriate changes of the connection the CFD simulation was used. The results obtained from numerical simulations led to final shape of the elbow connection between HP and LP turbine. The final shape of the connection significantly decreases the local and also the total pressure losses.

Keywords: high and low pressure turbine, pressure loss, elbow, CFD simulation

1. Introduction

The pressure of the European Union countries with stringent legislations concerning engine fuel consumption and emissions leads the engine industry to improve current machines and also to develop advanced technologies. The first step in improving the engines was using the turbocharger which use thermal energy from combustion gases. The turbocharger compresses air flowing into engine and more fuel can be injected to the engine. This process increases efficiency of combustions and also the mechanical power. The next effective way to improve efficiency and save energy produced by engine was two stage turbocharger. Two stage turbocharger is more complicated, but basically it is composed from high pressure (HP) and low pressure (LP) stage. This composition reaches higher pressure ratio and with inter cooling considerably higher efficiency than one stage turbocharger. Both leads to reduction of the fuel consumption and also emission production.

At this time two stage charging group provide more possibilities how to improve or change the regimes for defined applications. It is possible to change positions and sizes of both stages, use wastegates, different types of bypasses or to control the exhaust gas recirculation (EGR) and use variable turbine nozzle ring (VTA) and so on. Ref. 1, 2. All possibilities are effective, but it has to be designed for each application. In two stage composition there is also a space to optimize the connection elements between parts. Using suitable geometry of the connection elements it is possible to improve the total pressure losses and increase the total efficiency of the turbocharging.

This paper was created by support project of the Technological agency of Czech Republic (TAČR) and program Alfa. Ref. 3. The name of the project is "Development of two stage charging group for big reciprocating engines". The main goals of this project are to increase the efficiency and decrease the fuel consumption of own turbocharger through by optimization of flow parts, to improve system work through the regulation and control of internal parts. Based on defined goals

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the connection elbow between HP and LP stage was optimized. The final design of the connection was developed with many CFD calculations carried out in ANSYS CFX program.

2. Two stage unit composition

The model of the two stage turbocharger was supported by PBS Turbo. The example of two stage unit is composed from HP stage which is represented by TCX 14 as HP unit and LP represented by TCR 18 unit. The other possibility of the two stage composition produced by MAN Diesel & Turbo is HP and LP stage represented by TCX17 respectively TCR20. Ref. 4. The example of turbine side of the two stage turbocharger with description is presented in Fig 1.

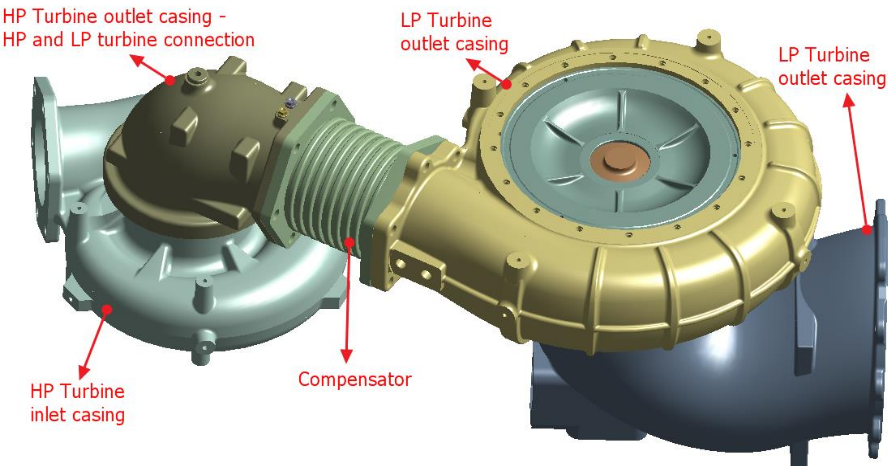

Fig 1. Example of two stage unit

The presented work was focused on design of the connection elbow (HP turbine outlet casing) between HP and LP turbine. The aim of design of connection elbow was to improve flow parameters of this elbow, decrease the pressure loss produced by inappropriate geometry and minimize negative influence for flow in LP turbine inlet casing.

3. Numerical analyses

For analysis of the HP and LP turbine connection ANSYS CFX 15.0 was used. Ref 5. The analyses of the HP and LP turbine connection were performed in two steps. In the first step the reference geometry of the connection was analyzed. In this step the defined input parameters with CFD results were correlated and critical locations of the elbow were found. The second step was focused on the design of new connection between HP and LP turbine. In this step the final geometry of elbow was prepared.

3.1 Reference geometry analysis

The reference geometry was based on the real configuration of the two stage turbocharge. The reference structural assembly was prepared in Creo Modeler. The assembly was imported into ANSYS Design Modeler and the inverse volumes of each component were created. The next step in the preparation of numerical model was meshing of created volumes in ANSYS Workbench. The volumes of the connection between HP and LP turbine with LP turbine volute and nozzle ring were meshed in one part. The HP impeller was meshed separately. The created mesh (see Fig 2) contains 4051994 elements (1486533 nodes) and the quality of the mesh was checked by y+ value. Wall y+ is dimensionless wall distance. This distance shows a quality of the CFD mesh near the static wall that is important for correct description of the turbulent flow model. Boundary layer density depends on the used turbulence model and flow structure. For SST (Shear stress transport) turbulence model y+ value is recommended between 11 and 300 for standard wall function. This value can be higher for enhanced wall function. CFX is capable for switching between standard and enhanced wall function. The maximum value of y+ was 249 and the average value was about 130. This mesh quality was affected by complicated geometry and was prepared as compromise between quality and calculation time.

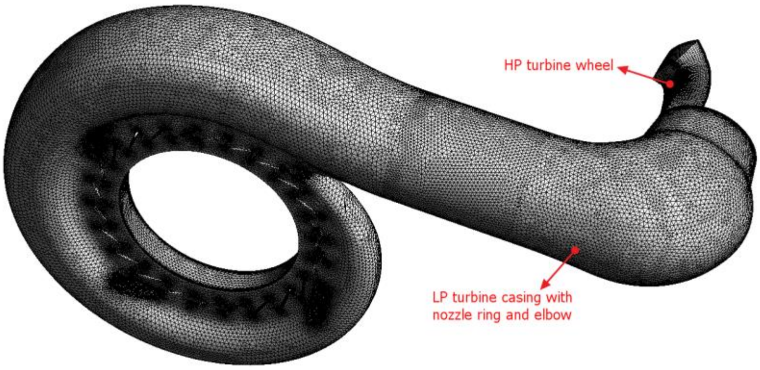

Fig 2. Mesh of reference geometry

Presented mesh was applied into the CFD model which was loaded and constrained according to input parameters. The input parameters were defined based on the 1D calculation prepared in PBS Turbo. The examples of input parameters are summarized in Tab. 1.

Tab. 1. Example of input parameters

	Velocity [m/s]	Temperature [K]	Pressure [bar a]	Rotational velocity [rpm]
Inlet HP	198.5	751.0	2.1	43200
Inlet LP	87.5	702.5		29800

The CFD model consists of rotational and stationary domain. The HP turbine wheel was rotational domain and LP turbine casing with nozzle ring and elbow were considered as stationary domain. Air with ideal gas properties was used for presented domains. The SST turbulent model was chosen. Applied boundary conditions for presented CFD model are described in Fig 3.

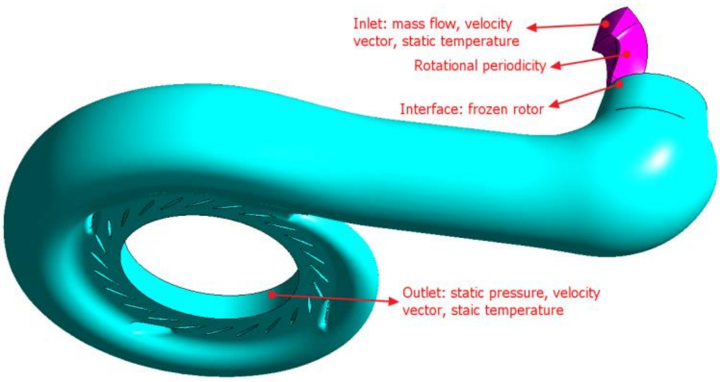

Fig 3. Boundary conditions

The CFD calculation was considered as steady state. From calculated results several variables characterizing the flow inside defined domains were monitored. The two basic parameters for assessment of the flow in the elbow were expressed:
Total pressure loss: Δp_{tot} [Pa]
Pressure loss coefficient: ζ [-]

$$\Delta p_{tot} = p_{tot\_in} - p_{tot\_out} \quad (1)$$

$$\zeta = \frac{p_{tot\_in} - p_{tot\_out}}{p_{d\_in}} \quad (2)$$

$p_{tot\_in}[Pa]$	Total pressure at the inlet
$p_{tot\_out}[Pa]$	Total pressure at the outlet
$p_{d\_in}[Pa]$	Dynamic pressure at the inlet

The values of pressure are calculated as area-averaged values on inlet and outlet surfaces. The evaluation of presented parameters were applied for reference and all calculated variants.

3.2 New design analyses

The aim of these calculations was to analyze the elbow connecting HP and LP turbine casing (see Fig 3) with regarding to pressure loss elimination. The new design of the elbow connection between HP and LP turbine casing was limited by geometry and space dimensions. The PBS Turbo defined this limitations. The most important limitations were connection dimensions (outlet from HP turbine and inlet of LP turbine) and maximum axial dimension (high) of the elbow (see Fig 3).

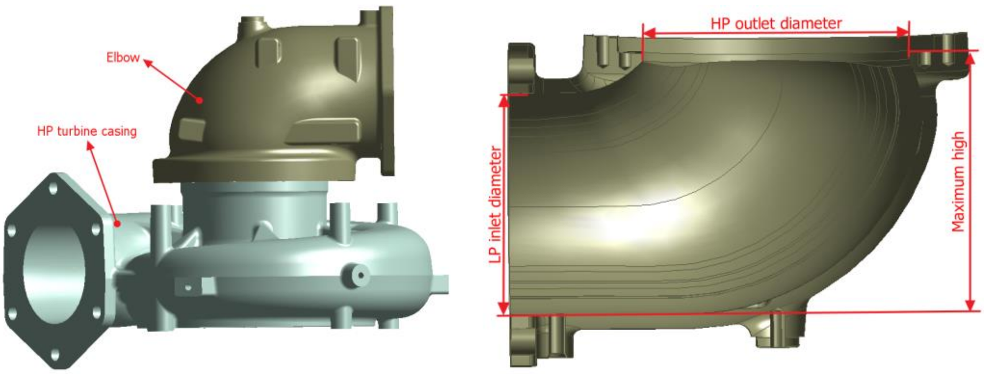

Fig 4. Reference connection of HP and LP turbine (left), dimensions limitation (right)

New design of the elbow in Creo Modeler was created. The geometry was composed of the central curve and five cross sections. Three of them are circular, and two of them are elliptic. One semi-major axis and two semi-minor axis (upper and lower part) dimensions define each modification. The cross sections area was constant. The example of the Creo model of geometry modification is presented in Fig 5. The comparison of the reference and new fluid domain geometry is depicted in Fig 5. Totally 22 elbow modifications were prepared. Several configurations of new design are described by corresponding parameters in Tab. 2. Each of new modifications of the elbow was meshed and imported into CFD model. The CFD analyses of new modifications were performed on the same CFD model and boundary conditions as in the reference model.

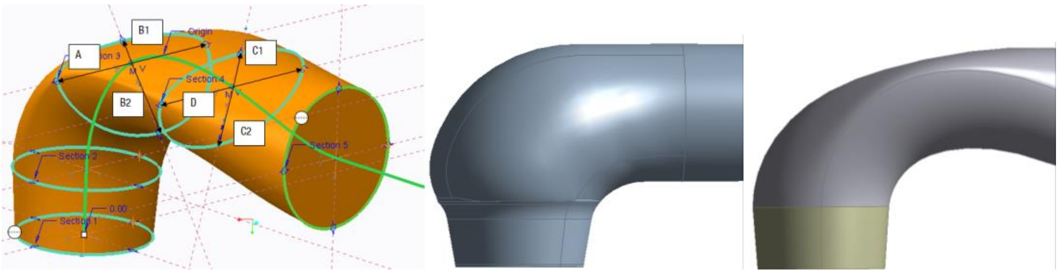

Fig 4. Creo model (left), reference domain (middle), new geometry domain (right)

Tab. 2. Parameters of elbow modifications

	A [m]	B1 [m]	B2 [m]	C1 [m]	C2 [m]	D [m]
Modification 1	0.200	0.05	0.180	0.080	0.156	0.195
Modification 2	0.200	0.05	0.180	0.080	0.156	0.195
Final Modification	0.200	0.05	0.180	0.085	0.170	0.180

4. Results and discussion

The CFD analysis of the HP and LP turbine connection was carried out. The CFD analysis was performed in two steps. The first step was focused on the reference geometry of the HP and LP turbine connection and the second step was focused on the elbow modification with regarding to pressure losses and also flow characteristics improvements in the whole domain.

4.1 Results of the reference geometry

Analysis of the reference geometry was based on the input parameters specified by PBS Turbo and separately presented in Tab. 2. The defined parameters were estimated from 1D calculation and several positions of the whole domain were specified (inlet of HP turbine through inlet of LP turbine). Defined parameters were correlated with CFD results and appropriate combinations of numerical scheme and boundary conditions were found. The correlation of 1D calculation and CFD results at HP turbine wheel outlet are presented in Tab.3. The evaluated results of reference geometry describe the possible critical location from the point of view of flow parameters. The evaluated results of the reference geometry are depicted in Fig 5 and Fig 6.

Tab. 3. Comparison of velocities components at the HP turbine wheel outlet

	1D calculation	CFD results
Axial	100%	105.6%
Radial	100%	103.0%
Circumferential	100%	117.8%

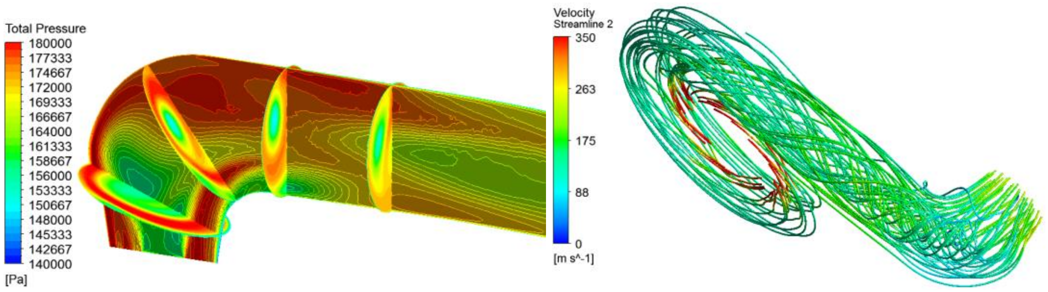

Fig 5. Total Pressure on elbow (left), Velocity Streamline in whole domain (right)

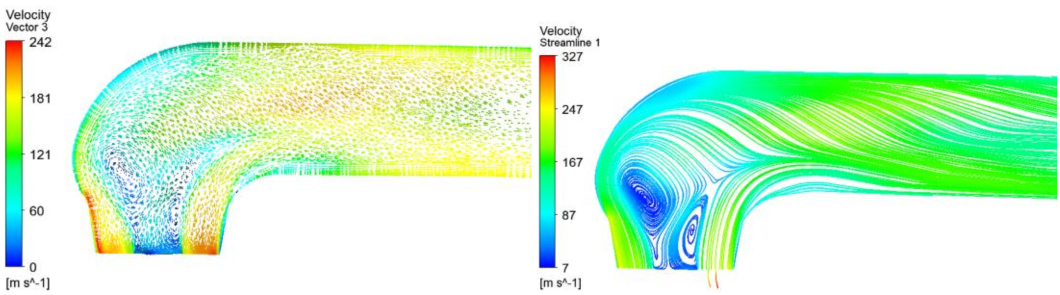

Fig 6. Velocity vectors on elbow (left), Velocity Streamline in elbow (right)

4.2 Results of new geometry

A total of twenty two modifications of the elbow connection between HP and LP turbine was created and calculated. The methodology of the elbow modification was described in chapter 3.2. The evaluation of each modification corresponding with evaluation presented for the reference geometry. The results of final modification are depicted in Fig 7 and Fig 8.

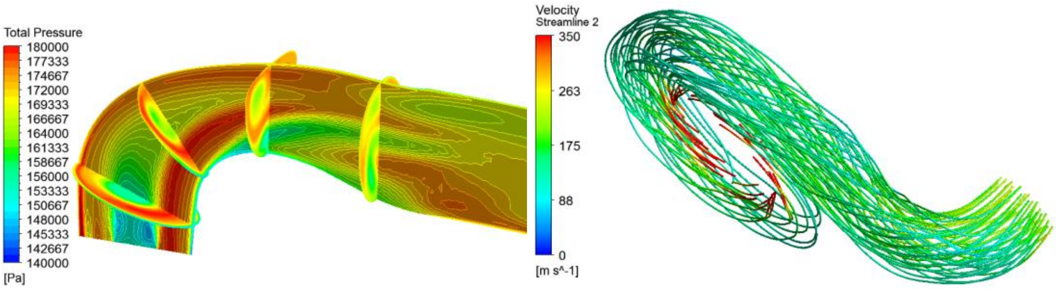

Fig 7. Total Pressure on elbow (left), Velocity Streamline in whole domain (right)

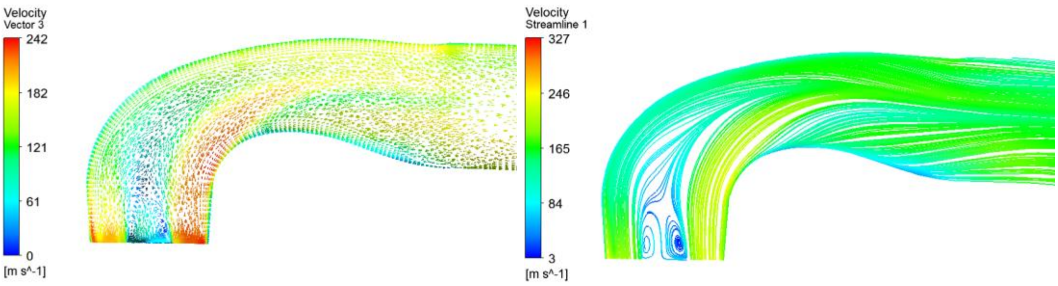

Fig 8. Velocity vectors on elbow (left), Velocity Streamline in elbow (right)

4.3 Discussion

The presented results of reference geometry confirms critical location of the elbow. HP turbine wheel generates significant vortex and air flow separation. The impact of the vortex is evident from Fig 6. This vortex closes about half of the flow area and losses of the elbow increase. This is caused by non-uniform cross sections of the reference geometry of the elbow in combination with quick change of the flow direction. Based on the reference geometry results the geometry modifications were prepared. The optimal shape of the elbow was found and the presented results confirmed improvements of the flow in the final modification of the elbow. The improvements of the flow can be seen in the Fig 8. The vortex region was significantly decreased and the velocity streamlines are more uniform. The total pressure distribution presented in Fig 7 also led to increasing of the HP turbine wheel efficiency. The improvements of new geometry are due to constant cross section in critical locations of the elbow and slower change of the flow direction. To compare the reference geometry with three best candidates of the elbow geometry, the total pressure losses and total pressure loss coefficients were evaluated. The evaluation of these parameters were carried out according to the methodology described in chapter 3.1 (eq.1 and eq.2).

Tab. 4. Evaluated parameters

	Δp_{tot} [Pa]	ζ [-]	Δp_{tot} [%]	ζ [%]
Reference	213679	2.887	-	-
Modification 1	209979	2.802	-1.73	-2.94
Modification 2	209912	2.801	-1.76	-2.98
Final Modification	209375	2.792	-2.01	-3.29

The total pressure loss coefficient of final modification was decreased about **3.3%** comparing to the reference geometry. This improvement of the final modification also had significant impact on other components of the whole domain. The first impact was on the total pressure on HP turbine wheel which led to efficiency increasing. The second impact was changing of the flow rotation in LP turbine inlet. The comparison of the flow rotation of the reference case and final modification is shown in Fig 9.

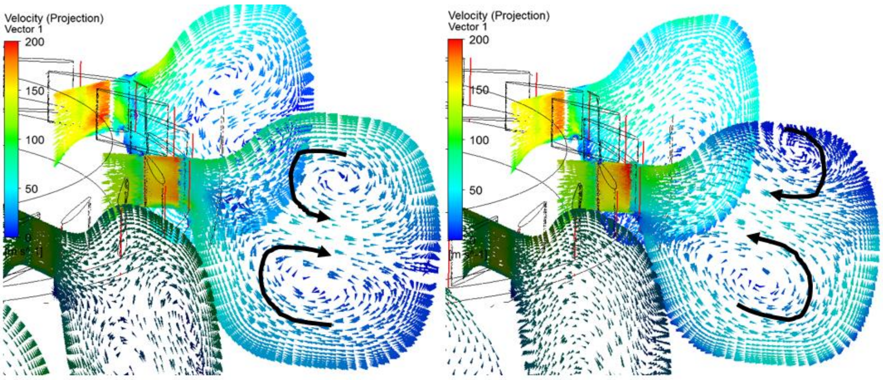

Fig 9. Comparison of tangential velocity vectors of reference (left) and modified geometry (right)

The changes of the flow rotation have also impact on the flow angle of the LP nozzle ring. The flow angle improvement is evident from velocity distribution plotted through the vanes. The geometry of the LP Turbine contains three reinforcement blades as well. These blades created the vortex regions at the reference geometry configuration. The new geometry improves these problematic regions and leads to decreasing of total pressure losses. The comparison of the velocity distribution in the nozzle ring of the reference configuration and new geometry were depicted in Fig 10 and Fig 11. The velocity evaluation was performed in the most critical section plane.

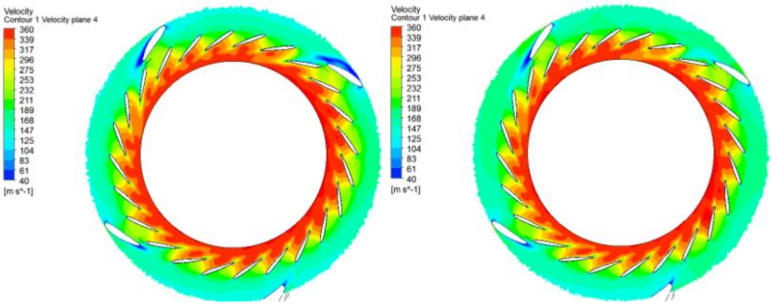

Fig 10. Comparison of velocity of reference (left) and modified geometry (right)

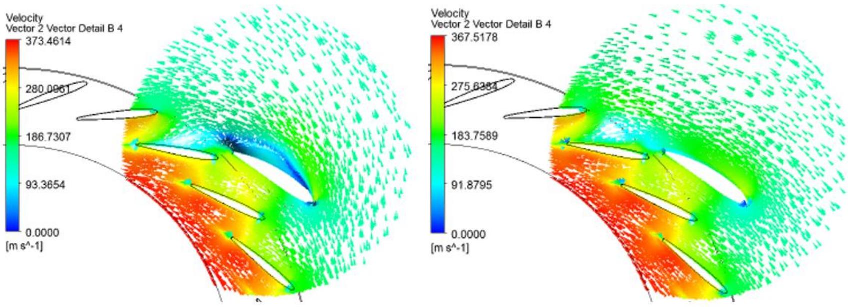

Fig 11. Detail of velocity vectors of reference (left) and modified geometry (right)

5. Conclusions

This paper is focused on the analysis of the HP and LP turbine connection. The connection is realized by the elbow. The reference geometry of the elbow was analyzed and the critical locations were found. The new modifications of the elbow were created and the final shape of the elbow was found. The new geometry of the elbow improves flow parameters of the elbow and also flow parameters in the whole domain. The improvements of new geometry positively affected the flow in HP turbine wheel and also the flow at input of the LP turbine. Provided analyses fulfilled defined requirements. The new design of the elbow was created in PBS Turbo and will be tested on real machine. The comparison of calculated and measured results is being prepared.

ACKNOWLEDGEMENT

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6. References

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