Numerical analysis on the external characteristic of torque converter based on dynamic mesh

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Abstract. For analysis of the flow field of torque converter’s start operating performance, the paper established a mathematical model and simulated the numerical value of YJ series hydrodynamic torque converter. In view of the partial impact fluid and cavitation phenomenon in processes such as multiple flow area coupling algorithms the sliding mesh method cannot achieve the flow parameters real-time transfer problems between the impellers. The model, established by dynamic mesh technology, set pump wheel and turbine blade for the rotating part of dynamic mesh, pick up each iterative step of pump wheel and turbine by the size of moment through the function, and deposited it into the text file. Through calculating the changes of text data, we can judge whether the result is stable. Take the comprehensive consideration of the stability, accuracy and efficiency during the calculation, set pressure-velocity coupling algorithm as the SIMPLE algorithm, set spatial discrete format as the first order up stream format, set turbulence model as the RNG K-\epsilon model, and realize the turbulence flow transient calculation of the hydrodynamic torque converter. Numerical simulation by the calculation was compared with the moment data from the experiments, the results show that the model established by dynamic mesh technology is more accurate and reliable. Thereafter, the pump wheel’s start-up rotate speed increased from 0 to 1000r/min gradually, then remained constant. Through the analysis, we concluded as follows: the pump wheel’s moment increased gradually, the value of the turbine’s moment was small, the flow increased slowly from the positive value in the early stage. Then the turbine’s moment increased gradually, the flow changed into negative value until stable.

1. Introduction
Hydraulic torque converter is one of the key components of the automatic speed control system in vehicles and engineering machinery, which equipped that, can automatically transform the speed and torque and so on. It is very difficult to accurately analysis flow condition of unsteady turbulent flow in component whether experimental methods or theory method in the past, because the movement of liquid in the runner is complex, three dimensional viscous, unsteady and turbulent flow. The most typical single-stage & phase, three component hydraulic torque converter is consisted of pump, turbine and stationary guide wheel, which are working together, mutual influence and have a largely relative flow. The internal characteristic of the hydraulic torque converter is quite complicated, for a type of YJ series hydraulic torque converter, blade number of the pump, guide wheel and turbine respectively.
is 29, 22 and 23. Cannot get any exchange relations of actual data at outlet and inlet among the wheels if just only choose a simple row and a runner geometric model to simulate. (Hydraulic torque converter transfer energy depends on kinetic energy of the liquid. Each point speed at the inlet surface is not the same size, while corresponding to previous export wheel, if take a fixed value will have a great effect on the calculation results). It cannot be correctly reflected the actual working condition if suppose one point speed is a fixed value in the steady state model, because the flow of liquid is a complex process of flow in the hydraulic torque converter, there is no any guarantee the speed is a certain value also cannot assure pump, wheel, turbine achieves to stability, so taking out all runners and with dynamic mesh technology to simulates combine with unsteady model [1-2].

2. Numerical simulation method

2.1 Calculation model of dynamic mesh

In the software of FLUENT, dynamic mesh model can be used to simulate the boundary movement caused the flow of the river shape changes with time [3-4].

For the flux $\phi$, In any control volume $V$, The boundary is in motion, the general conservation equation (1):

$$\frac{d}{dt} \int_V \rho \phi dV + \int_{\partial V} \rho \phi (\vec{\mu} - \vec{\mu}_i) \cdot dA = \int_{\partial V} \Gamma \nabla \phi \cdot dA + \int S_p dV$$

Type: $\rho$ is the fluid density, $\vec{\mu}$ fluid velocity vector, $\vec{\mu}_i$ Strain rate dynamic grid, $\Gamma$ is the diffusion coefficient for the diffusion coefficient, $S_p$ is the source of flux $p$, $dV$ used to describe the control boundary.

In equation (2), one can use a second-order backward difference:

$$\frac{d}{dt} \int_V \rho \phi dV = \frac{(\rho \phi dV)^{n+1} - (\rho \phi dV)^n}{\Delta t}$$

Type: $n$ and $n+1$ representation of the current time and the next time. The $n+1$ time on volume $V^{n+1}$ by equation (3).

$$V^{n+1} = V^n + \frac{dV}{dt} \Delta t$$

Type: $\frac{dV}{dt}$ is derivative control of time, in order to satisfy the law of conservation of the grid, the time derivative of the control volume by equation (4).

$$\frac{dV}{dt} = \int_{\partial V} \vec{\mu}_j \cdot dA = \sum_j \vec{\mu}_{s,j} \cdot A_j$$

Type $n_j$ for the control of body surfaces, $A_j$ is the surface area, each control volume face $\vec{\mu}_{s,j} \cdot A_j$ by equation (5).

$$\vec{\mu}_{s,j} \cdot A_j = \frac{\partial V_j}{\Delta t}$$

Type: $\partial V_j$ is the time step $\Delta t$ to control the surface expansion caused by volume change.

2.2 Model and Simulation

Modeling three dimensional model of pump, turbine and guide wheel with PROE is shown in figure 1. Then take out the materialization geometric model of leafy row and full runner is shown in figure 2. Meshing in ICEM (figure 3), input boundary conditions and at the last output mesh file.
2.3 UDF function compiling

According to the fluid mechanics calculation formula, the angular velocity increment of guide wheel had occurred by reason of fluid and Dynamic Loading.

\[ \Delta \omega = \frac{M + T}{m r^2} \cdot \Delta t \]

\[ \text{angular}[0] = \frac{M + T}{m r} \cdot \Delta t + v_0 \]

Type: \( m \) -Quality of the disc; \( \Delta t \) -Time Step; \( T \) - Dynamic Loading; \( M \) - fluid acts on turbine; \( \Delta \omega \) - The angular velocity increment; \( v_0 \) -initial velocity (the initial value is 0) ; \text{angular}[0] -angular velocity.

By UDF and dynamic grid technology the whole process of the pump opening is simulated and the motion characteristics of the pump are achieved. Set the speed changes with time, calculate the size of (around the center of rotation) that fluid acts on pump wheel and turbine through the Compute_Force_And_Moment () function, and deposited it into the text file through the fprintf () function. We can write dynamic grid control programs according equation (7) through the DEFINE_CG_MOTION () function [5-7].

2.4 Calculation method and boundary conditions

Dynamic mesh updates are mainly in the following 3 ways: Spring-based Smoothing, Dynamic Layering, and Local Remeshing. The author selected Spring-based Smoothing, and Local Remeshing two methods. The model uses RNG K – turbulence simulation, a discrimination of the convective term using to order upwind scheme, discrete diffusion term with two order accuracy central difference scheme, the coupling of velocity and pressure using the SIMPLE algorithm. For the characterization of blade movement, the blade movement function written in C and compiled in FLUENT, in the dynamic grid regional settings is set in the blade flap is a rigid body.

2.5 Convergence decision method

Take out the data from the text file, we achieve the relation of the applied moment on pump wheel and turbine changes with time. As shown in figure 4, pump and turbine torque is no longer change at an efficient condition (\( i=0.8 \), \( T=0.05s \)), that is considered convergence.
2.6 The simulation results
In the practical work, torque converter’s internal fluid flows as a dynamic process. The output terminal of turbine changes as external load changes, its rotational speed changes from zero to engine’s rated speed. By the reacting force of turbine flow, the rotational speed and torque acting on the pump wheel changed, and its variation follows the external characteristic curve of the engine. In order to take no account of the engine’s effect, engineering use the pump wheel, turbine’s speed ratio as reference to show torque converter’s performance, called it the torque converter original external characteristic curve. The horizontal axis of the torque converter’s ratio speed changes from 0 to 1, the longitudinal axis draw out torque ratio $K$, efficiency curve $\eta$. The related calculation formula is as follows:

$$\begin{align*}
K &= \frac{M_T^D}{M_P^D} \\
i &= \frac{n_T}{n_P} \\
\eta &= \frac{P_T}{P_p} = \frac{M_T^D \omega_T}{M_P^D \omega_p} = \frac{M_T^D n_T}{M_P^D n_P} = K \cdot i
\end{align*}$$

Through the simulation of torque converter we get the data (pump wheel 1000r/min), figure 7.

3. Typical condition analysis
On the condition ($t=0.04s$), figure 5 show that the pressure and speed of pump wheel’s blade are increased with the radius. When liquid flows across the pump wheel, the pressure increased gradually, achieved the maximum value at the outlet; then the liquid flows across the turbine, its pressure reduced. At the inlet of the pump wheel’s blade, there is a short blade working face area on the back that local pressure changed greatly, led to a great change on flow rate, as we could see in the blue zone. Because that the liquid flowing out of the stationary guide wheel had a low velocity, after the high-speed rotation switching of pump wheel and with its high speed centrifugation, formed the local low pressure area.

**Figure 5.** $t=0.04s$ Pressure contour.
4. Performance test
In the test, power and loading device adopt constant speed control, keep the pump wheel’s input speed as 1000r/min, the main purpose of constant test is to improve basis during the test of hydraulic torque converter’s steady state characteristics of simulation. Figure 6 shows the arrangement of the test bench. In tests, hydraulic pump motor is used as a power and loading device. Some project hydraulic torque converter is the tested object, its cycle circle diameter is 370mm, figure 7 shown the experimental data.

In figure 7, we draw out the torque converter’s external characteristic curves.

![Figure 6. Torque converter dynamic characteristic test bench](image)

Rotational speed control (input) torque control (output)
1, 7 speed sensor 2 power element 3, 5 torque sensor
4 torque converter (testing object) 6 Loading element

![Figure 7. External characteristic of hydraulic torque converter.](image)

5. Conclusions
(1) First, according to hydraulic torque converter model, extract the impeller flow channel model. Second, finite element method applies to hydraulic torque converter pump wheel and turbine runners model’s mesh generation.

(2) The paper provides another method to judge whether the flow field tend to be stable or not, and achieve each iterative step of simulation data to show transient flow field characteristics accurately.

(3) Multi blade row whole flow passage geometric model is simulated by Dynamic Mesh technology, it can predict the external characteristic of hydraulic torque converter accurately, so it has a practical guiding significance for us to design a hydraulic torque converter.

(4) Calculate torque converter’s transient flow distribution, compare and analyze the typical conditions, it has important theoretical value for learning torque converter’s internal turbulence structure deeply.

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