Effect of vanes diffuser geometric components on shape of the Q-H-curve

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Abstract. The article deals with the effect of the vanes diffuser geometric components at the inlet (downstream of an impeller) and at the outlet (upstream of the impeller) on the shape and steepness of the Q-H-curve. Intermediate stage comparative curves based on centrifugal pump tests are given with corrections to the vanes diffuser components were made. This allows changing steepness of the Q-H-curve. Comparative tests of the intermediate stage with different types of vanes diffusers (with continuous crossover channels and discontinuous crossover channels) are shown.

1. Introduction
Requirements on the steepness and the shape of the Q-H-curve are imposed upon for the majority of pumps being operated at thermal and nuclear power plants (TPP and NPP). First of all, this refers to centrifugal boiler feed pumps being operated in parallel, which are supplying in common network according to the power plant scheme. In this case, the saddle Q-H-curve can result in surging [1] leading to unstable operation of pumps. Therefore, the stable pump operation needs the flat Q-H-curve.

Another important requirement imposed on the Q-H-curve is to ensure a certain slope. So, according to GOST 22337-77 [2] and GOST 24464-80 [3], when designing the centrifugal boiler feed pumps, it is necessary to obtain the slope of Q-H-curve that doesn’t exceed 30%, and in some cases – not above 18%.

This is mainly due to the fact that a power plant pipeline system is designed for a certain pressure. Complete replacement of the whole pipeline system at the power plant is economically irrational decision. Further, entering the corrections to the geometry of hydraulic part of the pump allows changing the slope of the Q-H-curve without significant costs.

There is a fair amount of recommendations on hydraulic part design or further development of geometry after the pump tests to obtain a stable Q-H-curve with required steepness [4-6]. In this article, the effect of the vanes diffuser geometric elements on the shape and steepness of the Q-H-curve is considered.

2. Theoretical background
The physical origin of the saddle Q-H-curve is described in the literature sources [1,7]. The study of the impeller inlet shows that backflow is observed at pump partload. Backflow moves from the impeller outlet towards the diffuser return channels of the vanes diffuser and forms vortices that cause the head decrease at partload. The vortex at the impeller outlet also promotes an increase of hydraulic losses at partload (Figure 1).
In order to reduce vortex activity that can lead to the occurrence of the saddle Q-H-curve, a stationary vane cascade is usually installed upstream the impeller. Its function in the intermediate stage is performed by return channels vanes of the vanes diffuser.

3. Study of the vanes diffuser outlet components
The effect of the return channels vanes on the shape and steepness of the Q-H-curve was studied. Therefore, it is assumed that the vortex activity at low flows will increase with growing distance between rotating and stationary vane cascade (between the impeller blades at the inlet and the return channels vanes at the outlet); this will reduce the slope of the Q-H-curve due to the increase in hydraulic losses. However, as previously noted, increase of the vortex activity can lead to the saddle Q-H-curve. To obtain the flat Q-H-curve with the minimum steepness, the intermediate stage was designed in assembly with the impeller and vanes diffuser and tested at the testing facility as per single-stage scheme. This scheme means the vanes diffuser is installed upstream the stage to ensure flow parameters at the impeller input. In order to reduce the slope of the Q-H-curve and prevent the occurrence of the saddle in this curve the diameter d6 of the eight vanes out of the twelve has been trimmed at the outlet - for two vanes per one vane (Figure 2).

![Figure 1. Schematic of fluid flow field within the hydraulic part of multistage centrifugal pump at partload.](image)

![Figure 2. Vanes diffuser before trimming of the return channel vanes at the outlet (a) and after trimming of them (b).](image)
In this case, ratio of trimmed return channel vanes at the outlet to the impeller eye was \( \frac{d_6}{D_0} = 1.08 \), and ratio of the untrimmed ones was \( \frac{d_{6L}}{D_0} = 0.76 \).

Trimming of the return channel vanes was performed according to this scheme with understanding that four untrimmed vanes would sufficiently reduce the vortex activity for obtaining the flat Q-H-curve, and eight trimmed vanes would form a vortex zone that increases hydraulic losses at partload. Consequently, the head as well as the steepness of the Q-H-curve would decrease.

Comparative analysis of the test results (Figure 3) showed that the Q-H-curve after trimming of the diffuser vanes remained the flat one at partload, and Q-H-curve steepness decreased by 6%. The efficiency value and best efficiency point (BEP) were not changed.

Based on obtained results it could be make a conclusion that a judicious mix of blade diameters of return channels at the outlet and their quantity (trimmed and untrimmed return channels) allows to decrease the steepness of the Q-H-curve and prevent the occurrence its saddle shape simultaneously.

![Figure 3](image)

Figure 3. Comparative curves of pump stage being tested with vanes diffuser before trimming of return channels and after trimming of them.

4. **Studies of vanes diffuser components at the inlet**

As previously noted, vortices form at partload not only at inlet of the impeller, but at outlet of it.

Considering diffuser channels of the vanes diffuser are a stationary vane cascade placed downstream of the impeller it could be supposed that they also have an effect on the vortex activity. It is possible to extend the inner space between grids due to trimming of leading edges of the diffuser channels (Figure 4). Herein, it could be supposed the the inner space between a rotating vane cascade (the impeller outlet) and stationary vane cascade (the diffuser inlet) extends and results in increasing of the vortex activity at partload and hydraulic losses. Due to this the head decreases at partload. At the same time the selection of the judicious mix \( \frac{d_3}{d_2} \) (the gap between the diameter of the vanes diffuser channels - \( d_3 \) and diameter of impeller outlet – \( d_2 \)) [8] allows for vortex intensity to be not so significant, and it allow to avoid the occurrence of saddle Q-H-curve.
Figure 4. Sketch of trimming of vanes diffuser leading edges.

Figure 5 shows comparative curves of the stage with trimmed leading edges of the diffuser channels in the vanes diffuser.

Figure 5. Comparative curves of pump stage tested with vanes diffuser before trimming of vanes diffuser leading edges and after trimming.

Comparative analysis showed that trimming of the vanes diffuser leading edges resulted in Q-H-curve decrease of 5%, and efficiency wasn't changed.

5. Study of effect of vanes diffuser design type
Two types of the vanes diffusers can be applied in a hydraulic part of a multistage pump (Figure 6): a vanes diffuser with continuous crossover channels (a – the continuous vanes diffuser) and a vanes diffuser with discontinuous crossover channels (b – the discontinuous vanes diffuser).
Figure 6. Design variants of vanes diffusers: (a) continuous vanes diffuser; (b) discontinuous vanes diffuser.

When studying a working process a numerical calculation was carried out for the vanes diffuser [9] by simulation of fluid flow. It was indicated that the flow pattern within discontinuous and continuous vanes diffuser has the main difference within the crossover channel at the BEP. The flow within the channel is observed in the continuous vanes diffuser, and mixing of flows effluent the diffuser channels in combination with the flow rotating in annular space is observed in the discontinuous vanes diffuser. We can suppose that a separation flow forming the vortex zone at partload appears in the turning area of the crossover channel of the continuous vanes diffuser that promotes to increase velocity and hydraulic losses and, consequently, decrease in the head. Therefore, absence of the continuous channel and presence of the annular space in the discontinuous vanes diffuser promote to reduce the vortex zone at partload. Moreover, fundamental hydraulic losses in the crossover channel of the discontinuous vanes diffuser are associated with matching of flow angle and inlet blade angles. According to the studies [10], the blade angle of the discontinuous vanes diffusers is essentially independent of the operation conditions. Therefore, hydraulic shock losses at partload that depend on the flow angle are expected to be virtually the same as the hydraulic losses at the BEP. It means that total hydraulic losses occurring at partload are less in the discontinuous vanes diffusers than in discontinuous ones. Consequently, the stages with the discontinuous vanes diffusers will always have the greater head at partload than the stages with the continuous ones under otherwise equal conditions.

These considerations have been empirically examined. Two types of the vanes diffusers were manufactured for this purpose (the continuous vanes diffuser and discontinuous vanes diffuser). They were tested in assembly with a pump and the same impellers at the testing facility.

Figure 7 gives test results; index 1 designates a curve of a pump with the continuous vanes diffuser and index 2 designates a curve of a pump with the discontinuous vanes diffuser.

An analysis of performance curves confirmed the foregoing premises. It should be noted that replacement the continuous vanes diffusers on the continuous ones allowed to correct the shape of the Q-H-curve (to remove the saddle curve) while the maintaining the efficiency level and the BEP position.
Figure 7. Comparative curve of pumps tested with the vanes diffusers of the different types.

6. Conclusions

1. The vanes diffuser geometrical elements have influence on the shape and steepness of the Q-H-curve.
2. Performed studies at vanes diffuser outlet and impeller inlet have been shown that trimming of return channel vanes at the outlet of the vanes diffuser allowed to decrease the slope of the Q-H-curve while maintaining its stable shape.
3. Performed studies at vanes diffuser inlet and impeller outlet have been shown that trimming of the leading edge of the vanes diffuser diffuser channels allowed to decrease the slope of the Q-H-curve.
4. Replacement the continuous vanes diffuser for the discontinuous one in the stage allows increasing steepness of the Q-H-curve due to a head rise at partload.

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