COMPARATIVE ANALYSIS OF AN IMPELLER GEOMETRY AT DIFFERENT HEADS OF A PUMP

**Abstract:** Impellers designing with ten blades at different heads of a hydraulic pump (from 5 to 25 m) by means of the Ansys Workbench software environment was carried out in the article. Three-dimensional models are presented and elements description of the radial impeller of the pump is given. Calculations of the impellers geometry were carried out at volume fluid flow rate (water) of 300 m³/h. Profiles and geometric dimensions of the impeller blades are obtained in the spans: 0 and 1. It is determined that the radial impellers are recommended to be used at the pump head of 20 – 25 m. The most stable characteristic of the pump operation is observed in this range of heads. Tangential, meridional and relative velocities of fluid flow at the impeller blades are calculated.

**Key words:** a radial impeller, a blade, a pump head, theta, beta, thickness, a shroud, a hub, fluid, a pump.

**Language:** English

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**Introduction**

Energy conversion of rotation of a motor shaft into fluid flow energy is performed by means of a radial impeller. Fluid moves from a center to a periphery of a device, i.e. centrifugal force occurs at rotation of the impeller. Vacuum is created in a central part of the radial impeller, which provides fluid supply under pressure to a suction pipe of the pump. The impellers are made of cast iron or steel.

Main elements of the radial impeller [1 – 10] are presented by the wire three-dimensional models in the Fig. 1 – 13. In a shroud it is located a hub with blades (the impeller). A gap is provided between maximum outer diameters of the shroud and the...
impeller, which is an outlet for moving fluid. Fluid is pumped into an inlet. The minimum and maximum diameters of the inlet equal to the minimum diameter of the hub and the minimum inner diameter of the pump shroud. The impeller blade profile is presented by end surfaces of the blades at the hub and the shroud. A periodic boundary defines a contour of a calculated cavity, which is located between the hub and the shroud. A centroid divides a passage area of the impeller in half. Mean lines characterize a number of the meridional flow surfaces. The camber surface of the blade is characterized by a maximum ordinate of the mean line of the profile. This parameter depends on the inlet angle and the outlet angle of fluid. The inlet and outlet edges of the blade are rounded, and a value of a rounding radius should be selected taking into account the requirements of hydrodynamics. The throat surface is defined as a distance between the low theta side and the high theta side along the blade surface. The radial impeller is built in the BladeGen module of the Ansys Workbench software environment.

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Figure 1 – The hub of the radial impeller.

Figure 2 – The shroud of the radial impeller.

Figure 3 – The inlet of the radial impeller.

Figure 4 – The outlet of the radial impeller.
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**Figure 5** – The periodic of the radial impeller.

**Figure 6** – The blades of the radial impeller.

**Figure 7** – The blades hub end of the radial impeller.

**Figure 8** – The blades shroud end of the radial impeller.
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Figure 9 – The blades centroid of the radial impeller.

Figure 10 – The mean lines of the radial impeller.

Figure 11 – The camber surfaces of the radial impeller.

Figure 12 – The throat surfaces of the radial impeller.
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Figure 13 – The 3D model of the radial impeller.

The geometry calculation of the pump impellers

Initial operating conditions of the pump and the data for the geometry calculation of the impellers are presented in the table 1.

The geometry calculation of the impellers was carried out 5 times at the different values of the pump head (H). The pump head is the sum of static and velocity heads.

Table 1. Operating conditions of the pump and the geometry of the radial impeller.

| Operating conditions |
|----------------------|
| **Duty**             |
| Rotational speed     | 1500 rpm            |
| Volume flow rate     | 300 m³/hr           |
| Density              | 1000 kg/m³          |
| Pump head             | 5/10/15/20/25 m     |
| Inlet flow angle     | 90 deg              |
| Merid. velocity ratio| 1.1                 |

| **Efficiencies** |
|-----------------|
| Hydraulic       | 0.874              |
| Volumetric      | 0.97               |
| Mechanical      | 0.948              |
| Pump            | 0.804              |

| **Geometry** |
|--------------|
| **Hub diameter**       |
| Shaft min. diam. factor| 1.1                |
| Dhub/Dshaft            | 1.5                |
| **Tip diameter**       |
| Head coefficient       | 0.46               |
| Tip diameter           | 280 mm             |
| **Leading edge blade angles** |
| Hub blade angle        | 27 deg             |
| Mean blade angle       | 19 deg             |
| **Trailing edge blade angles** |
| Blade angle            | 22.5 deg           |
| Rake angle             | 0 deg              |
| **Shroud**             |
| Incidence              | 0 deg              |
| Shroud blade angle     | 16 deg             |
| **Miscellaneous**      |
| Number of blades       | 10                 |
| Thickness/tip diam.    | 0.03               |
| Hub inlet draft angle  | 30 deg             |
The pump head varied in the range of 5 – 25 m. The remaining geometric and operating parameters of the radial impellers were constant. Volume flow rate of fluid by the value of 300 m³/h was required at rotation speed of the radial impeller of 1500 rpm. Water with density of 1000 kg/m³ was adopted as working fluid. The inlet flow angle is the angle at the leading edge of the impeller. The value of the inlet flow angle of fluid was taken 90 degrees for performing of the calculations. Approach flow without pre-rotation occurs at the given value of the inlet flow angle. The meridional velocity ratio is pattern of the linear velocity profile from the hub to the shroud at the leading edge of the radial impeller. Meridional velocity is less at the hub of the radial impeller at the value of the meridional velocity ratio of 1.1.

The efficiency coefficient of the pump is defined as the coefficients product of hydraulic, volumetric, and mechanical efficiencies. The coefficients values characterize losses of useful work of the pump at friction of the mating elements of the device.

The shaft minimum diameter factor is the safety factor of the pump shaft in conditions of maximum allowable shear stress of material. The one tenth of the factor (1.1) is increasing of the shaft diameter by 10%. The ratio of the impeller hub diameter to the shaft diameter (Dhub/Dshaft) was taken 1.5. The tip diameter was set to 280 mm at the adopted pump head coefficient equal to 0.46. The leading edge blade angles are characterized by the hub blade angle (27 degrees) and the mean blade angle (19 degrees). The trailing edge blade angles are characterized by the blade angle (22.5 degrees) and the rake angle (0 degrees). The blade angle at the shroud by the value of 16 degrees was adopted at designing of the impeller. The incidence angle at the shroud was selected by default 0 degrees.

The adopted number of the impellers blades is 10 pieces. This number of the blades gives greater control over flow direction in the pump impeller. The ratio of thickness to the tip diameter is used for determining of the impeller blade thickness. The ratio of thickness to the tip diameter equal to 0.03 indicates about a low probability of blockage to fluid flow. The hub inlet draft angle (30 degrees) is the angle between the hub and the horizontal line at the hub inlet. The hub radius of the pump impeller depends on the value of this angle.

The calculated parameters of the impeller elements in the different sections (from stub to peripheral) are presented in the summary table 2.

| Parameters | Pump head, m |
|------------|-------------|
|            | 5  | 10 | 15 | 20 | 25 |
| **Span: 0** |    |
| 1. Layer   |    |
| B2B throat length 0 | 23.2998 | 30.7859 | 33.0261 | 35.0692 | 36.0579 |
| Segment 0 (0 to 0) | 23.2997 | 30.7559 | 32.9884 | 35.018 | 36.0186 |
| Crv throat length 0 | 23.2997 | 30.7559 | 32.9884 | 35.018 | 36.0186 |
| LE pitch | 32.6379 | 34.94 | 38.1708 | 42.7978 | 46.9774 |
| TE pitch (S) | 64.7102 | 97.6394 | 121.378 | 138.501 | 152.753 |
| Centroid:Z | -10.3934 | -6.99712 | -3.1923 | -1.75024 | -1.5597 |
| Centroid:R | 48.4668 | 67.2025 | 81.5823 | 92.5206 | 101.509 |
| Centroid:T | -38.8 | -38.3 | -45.6 | -54.0 | -61.0 |
| Centroid:Mp | 0.589379 | 0.805987 | 0.877109 | 0.864041 | 0.849385 |
| Centroid:M | 23.0234 | 38.4933 | 48.5125 | 54.0931 | 58.5061 |
| Airfoil area | 327.405 | 582.996 | 893.181 | 1224.9 | 1574.36 |
| 2. Blade & layer |    |
| 3D meanline length | 67.8987 | 99.3529 | 130.444 | 158.032 | 183.85 |
| Camber length | 67.9001 | 99.3554 | 130.448 | 158.038 | 183.859 |
| Cord length (C) | 67.1055 | 96.7405 | 127.599 | 155.85 | 182.175 |
| Meridional length (M) | 39.9246 | 65.4698 | 83.0066 | 93.8869 | 102.905 |
| Stagger angle | -53.5 | -47.4 | -49.4 | -53.0 | -55.6 |
| Solidity (C/S) | 1.03702 | 0.990793 | 1.05126 | 1.12526 | 1.19261 |
| Pitch cord ratio (S/C) | 0.964305 | 1.00929 | 0.951243 | 0.888686 | 0.838494 |
| 3. Bezier |    |
| Stagger angle | 51.8 | 43.6 | 45.5 | 49.8 | 53.0 |
| LE theta angle | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| LE beta angle | 41.5 | 31.4 | 33.5 | 39.6 | 44.1 |
| TE beta angle | 67.7 | 68.1 | 67.9 | 67.7 | 67.6 |
| LE wedge angle | -2.2 | -2.2 | -2.8 | -3.1 | -3.2 |

The calculated parameters of the impeller elements in the different sections (from stub to peripheral) are presented in the summary table 2.
|              | ISRA (India) | SIS (USA) | ICV (Poland) | SIF (France) |
|--------------|--------------|-----------|--------------|--------------|
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|----------------|--------------|----------------|------------------|
|                | 1.500        | 0.564          | 5.667            |

| Advanced side1 point | Value | Advanced side2 point | Value |
|----------------------|-------|----------------------|-------|
| First point %M'      |       | First point %M'      |       |
| Last point %M'       |       | Last point %M'       |       |
| Linear point %M'     |       | Linear point %M'     |       |

| 1. Layer | Value | 2. Blade & layer | Value |
|----------|-------|-----------------|-------|
| B2B throat length 0 | 26.0818 | 3D meanline length | 77.6836 |
| Segment 0 (0 to 0)   | 26.0781 | Camber length     | 77.6849 |
| Crv throat length 0  | 26.0781 | Cord length (C)   | 77.4054 |
| LE pitch             | 47.3035 | Meridional length (M) | 39.171 |
| TE pitch (S)         | 75.8122 | Stagger angle     | -59.6 |
| Centroid:Z           | -25.891 | Solidity (C/S)    | 1.02102 |
| Centroid:R           | 59.7521 | Pitch cord ratio (S/C) | 0.979417 |
| Centroid:T           | -38.0  |                  |       |
| Centroid:Mp          | 0.420255 |                |       |
| Airfoil area         | 373.976 |                |       |

Span: 0.2500

| 1. Layer | Value | 2. Blade & layer | Value |
|----------|-------|-----------------|-------|
| B2B throat length 0 | 28.1162 | 3D meanline length | 88.7124 |
| Segment 0 (0 to 0)   | 28.0973 | Camber length     | 88.7137 |
| Crv throat length 0  | 28.0973 | Cord length (C)   | 88.6499 |
| LE pitch             | 61.9692 | Meridional length (M) | 38.881 |
| TE pitch (S)         | 86.9141 | Stagger angle     | -64.0 |
| Centroid:Z           | -41.6684 | Solidity (C/S)    | 1.01997 |
| Centroid:R           | 70.985  | Pitch cord ratio (S/C) | 0.98042 |
| Centroid:T           | -37.2  |                  |       |
| Centroid:Mp          | 0.320383 |                |       |
| Airfoil area         | 427.293 |                |       |

Span: 0.5000

| 1. Layer | Value | 2. Blade & layer | Value |
|----------|-------|-----------------|-------|
| B2B throat length 0 | 28.6997 | 3D meanline length | 88.7124 |
| Segment 0 (0 to 0)   | 28.6716 | Camber length     | 88.7137 |
| Crv throat length 0  | 28.6716 | Cord length (C)   | 88.6499 |
| LE pitch             | 76.6348 | Meridional length (M) | 38.881 |

Span: 0.7500
Main integral characteristics of the cross sections of the profiled pump impellers blades are given in the table. \( \text{Span 0.000} \) is the stub section of the impeller blade; \( \text{span 1.000} \) is the peripheral section of the impeller blade. The calculation of a pitch at the leading edge of the blade (\( LE \) pitch), the pitch at the trailing edge of the blade (\( TE \) pitch), the airfoil area, a cord length (\( C \)), the meridional length (\( M \)), the stagger angle, solidity (\( C/S \)), the pitch cord ratio (\( S/C \)) and the other parameters was performed.
At considering of the blades characteristics in the stub and peripheral sections, it could be argued that:

1. The pitch at the leading edge of the impeller blade in the stub section increases with increasing of the pump head, and the pitch in the peripheral section decreases.

2. The pitches at the trailing edge of the impeller blade are the same in the stub and peripheral sections at the pump heads of 20 and 25 m.

3. Decreasing of the airfoil area of the impeller blade is almost twice observed at the pump head of 5 m.

The contours and the dependencies graphs of the main elements geometry of the impellers from the pump head are presented in the Fig. 14 – 45. The flowing parts of the impellers blades and fluid flow direction are displayed in the meridional configuration. The blade channels (two adjacent impeller blades) are shown in the Fig. 15. $\theta$ is circumferential coordinate of the mean line points in a cylindrical coordinate system, an axis of which coincides with the axis of an engine. $\beta$ (axial) is the angle between a tangent to the mean line of the profile and the axis of the impeller. $\theta$ changes in the range of 0…100 degrees. The maximum negative value of the angle is reached at the trailing edge of the blade at the pump head of 25 m. $\beta$ changes in the range of 120…165 degrees. The value of the angle decreases in the stub section of the impeller blade. Thickness changing of the impellers blades is in the range of 0.09 to 0.5 mm. Changing of the inverse radius of curvature of the blade at the hub and the shroud of the impeller in meridional fraction from the leading edge to the trailing edge are shown in the Fig. 19. Maximum increasing of the inverse radius of curvature of the blade is observed at the trailing edge. The dependencies of the inverse radius of curvature of the blade in meridional fraction from the leading edge to the trailing edge (the parameters $\text{mean}$, $\text{side1}$ and $\text{side2}$) are presented in the Fig. 20. $\text{Mean}$ is a default option and specifies that the $\theta$ values are for location of the mean line. $\text{Side1}$ specifies that the $\theta$ values locate the side of the blade (at the larger $\theta$ value). $\text{Side2}$ specifies that the $\theta$ values locate the side of the blade (at the smaller $\theta$ value). The inverse radius of curvature of the impeller blade (the leading edge) at $\text{mean}$ and $\text{side1}$ has the positive values. The values changing of $\theta$ and $\beta$ at the leading and trailing edges of the impellers blades in the range of the stub/peripheral sections are defined in the Fig. 21 and 22. $\theta$ at the leading edge of the blade is 0 degrees; $\theta$ at the trailing edge is 65…92 degrees. In the stub section $\beta$ at the leading edge of the blade is more than at the trailing edge, and in the peripheral section is vice versa. A height distribution of the minor and major radii of ellipses of the leading edge of the impeller blade is shown in the Fig. 23. The relative height of the impeller blade is plotted along the horizontal axis, the values of the edges radii in mm are plotted along the vertical axis. Changing of the lean angle of the impeller blade at the hub and the shroud from the relative axial chord is calculated in the Fig. 24. Significant changing of the values of this angle is determined at the pump head of 20 – 25 m. The quasi-orthogonal area was calculated with and without the flow angle correction of fluid, with and without the blades. It is determined that the quasi-orthogonal area of the blade with correction in 2 – 3 times is less than the quasi-orthogonal area of the blade without correction. The airfoil areas of the impellers blades in the height are calculated on the graphs (the Fig. 26). The airfoil area of the blade from the hub to the shroud increases linearly at the pump head of 5 m. The airfoil area decreases according to a non-linear law at the pump head of 15 – 20 m at the distance from the stub section to the mean line, and the airfoil area increases according to the non-linear law at the distance from the mean line to the peripheral section. The maximum spherical diameter at the leading edge of the impeller blade is 85 mm at the pump head of 10 m. This is the maximum value of this parameter. The dependencies of $\theta$ and $\beta$ from $M$-Prime (the current blade angle with the horizontal axis using the radius normalized meridional distance), $M$ (the current blade angle with the horizontal axis using the meridional distance), $Z$ (the current blade angle with the horizontal axis using axial location) and $R$ (the current blade angle with the horizontal axis using radial location) are shown in the Fig. 28 – 31. Changing of $\theta$ and $\beta$ from the stub to peripheral sections of the impellers blades are presented in the Fig. 32 – 39. $\theta$ from $M$ at the leading edge of the blade (in all sections) is 0 degrees; $\theta$ from $M$ at the trailing edge is 65 degrees. The impeller blade profile has maximum curvature at the high pump heads. The dependencies of $\beta$ from $\theta$ for all sections are presented in the Fig. 40. It is noted that in the stub section $\beta$ decreases, and in the peripheral section $\beta$ increases.

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**Figure 14** – The meridional configuration of the impeller blade: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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Figure 15 – The blade-to-blade view: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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Figure 16 – Theta (blade location): A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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| JIF              | 1.500         |
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| PHHH (Russia)    | 0.156         |
| ESJI (KZ)        | 5.015         |
| IBI (India)      | 4.260         |
| ICV (Poland)     | 6.630         |
| PIF (India)      | 1.940         |
| ESJI (KZ)        | 5.015         |
| SJIF (Morocco)   | 5.667         |

Figure 17 – Beta (blade angle): A) $H = 5\ m$, B) $H = 10\ m$, C) $H = 15\ m$, D) $H = 20\ m$, E) $H = 25\ m$. 
Figure 18 – Normal thickness: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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**Figure 19** – The meridional curvature graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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ESJI (KZ) = 5.015
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Figure 20 – The blade-to-blade curvature graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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| SJIF (Morocco)  | 5.667         |

Figure 21 – The LE/TE theta graph: A) \(H = 5\) m, B) \(H = 10\) m, C) \(H = 15\) m, D) \(H = 20\) m, E) \(H = 25\) m.
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IBI (India) = 4.260

SJIF (Morocco) = 5.667

Figure 22 – The LE/TE beta graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 23 – The LE/TE parameter graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
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| GIF (Australia)                 | 0.564         |
| JIF                             | 1.500         |
| PIIH (Russia)                   | 0.156         |
| ESJI (KZ)                       | 5.015         |
| IBI (India)                     | 4.260         |
| SIS (USA)                       | 0.912         |
| ICV (Poland)                    | 6.630         |
| RIJC (Russia)                   | 0.156         |
| ESJI (KZ)                       | 5.015         |
| SJIF (Morocco)                  | 5.667         |

**Figure 24** – The blade lean angle graph: A) $H = 5\,\text{m}$, B) $H = 10\,\text{m}$, C) $H = 15\,\text{m}$, D) $H = 20\,\text{m}$, E) $H = 25\,\text{m}$. 
**Impact Factor:**

| Journal                  | Impact Factor |
|--------------------------|---------------|
| ISRA (India)             | 3.117         |
| SIS (USA)                | 0.912         |
| ICV (Poland)             | 6.630         |
| ISI (Dubai, UAE)         | 0.829         |
| PIIH (Russia)            | 0.156         |
| PIF (India)              | 1.940         |
| GIF (Australia)          | 0.564         |
| ESJI (KZ)                | 5.015         |
| IBII (India)             | 4.260         |
| JIF                      | 1.500         |
| SJIF (Morocco)           | 5.667         |

**Figure 25** – The quasi-orthogonal area graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
### Impact Factor:

| Source          | Impact Factor |
|-----------------|---------------|
| ISRA (India)    | 3.117         |
| SIS (USA)       | 0.912         |
| ICV (Poland)    | 6.630         |
| ISI (Dubai, UAE)| 0.829         |
| РИНЦ (Russia)   | 0.156         |
| PIF (India)     | 1.940         |
| GIF (Australia) | 0.564         |
| ESJI (KZ)       | 5.015         |
| JIF             | 1.500         |
| SIS (USA)       | 0.912         |
| РИНЦ (Russia)   | 0.156         |
| ESJI (KZ)       | 5.015         |
| JIF             | 1.500         |
| ICV (Poland)    | 6.630         |
| SIS (USA)       | 0.912         |
| РИНЦ (Russia)   | 0.156         |
| ESJI (KZ)       | 5.015         |
| JIF             | 1.500         |
| ICV (Poland)    | 6.630         |
| SIS (USA)       | 0.912         |
| РИНЦ (Russia)   | 0.156         |
| ESJI (KZ)       | 5.015         |
| JIF             | 1.500         |
| ICV (Poland)    | 6.630         |

**Figure 26** – The airfoil area graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

ISRA (India) = 3.117  SIS (USA) = 0.912  ICV (Poland) = 6.630
ISI (Dubai, UAE) = 0.829  PIIHI (Russia) = 0.156  PIF (India) = 1.940
GIF (Australia) = 0.564  ESJI (KZ) = 5.015  IBI (India) = 4.260
JIF = 1.500  SJIF (Morocco) = 5.667

Figure 27 – The maximum diameter graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
### Impact Factor:

| Source                        | Impact Factor |
|-------------------------------|---------------|
| ISRA (India)                  | 3.117         |
| ISI (Dubai, UAE)              | 0.829         |
| GIF (Australia)               | 0.564         |
| JIF                           | 1.500         |
| SIS (USA)                     | 0.912         |
| PIIH (Russia)                 | 0.156         |
| ESJI (KZ)                     | 5.015         |
| ICV (Poland)                  | 6.630         |
| PIF (India)                   | 1.940         |
| IBI (India)                   | 4.260         |
| GIF (Australia)               | 0.564         |
| JIF                           | 1.500         |
| SJIF (Morocco)                | 5.667         |

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**Figure 28** – The blade angle graph vs. M-prime position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

| Journal          | Impact Factor |
|------------------|---------------|
| ISRA (India)     | 3.117         |
| ISI (Dubai, UAE) | 0.829         |
| GIF (Australia)  | 0.564         |
| JIF              | 1.500         |
| ISIC (Russia)    | 0.156         |
| ESJI (KZ)        | 5.015         |
| IBI (India)      | 4.260         |
| SIS (USA)        | 0.912         |
| GIF (Australia)  | 0.564         |
| ICV (Poland)     | 6.630         |
| RIHNC (Russia)   | 0.156         |
| ESJI (KZ)        | 5.015         |
| SJIF (Morocco)   | 5.667         |

Figure 29 – The blade angle graph vs. Meridional position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

| Journal           | ISRA (India) | SIS (USA) | ICV (Poland) | ISI (Dubai, UAE) | PIIH (Russia) | PIF (India) | GIF (Australia) | ESJI (KZ) | IBI (India) | JIF | SISI (USA) | ESJI (KZ) | ICV (Poland) | ISI (Dubai, UAE) | PIIH (Russia) | PIF (India) | GIF (Australia) | ESJI (KZ) | JIF |
|-------------------|--------------|-----------|--------------|------------------|----------------|-------------|----------------|-----------|-------------|-----|-----------|-----------|--------------|----------------|---------------|-------------|----------------|-----------|-----|
|                   | 3.117        | 0.912     | 6.630        | 0.829            | 0.156          | 1.940       | 0.564          | 5.015     | 4.260       | 1.500| 0.912     | 5.015     | 6.630        | 0.829          | 0.156         | 1.940       | 0.564          | 5.015     | 1.500 |

Figure 30 – The blade angle graph vs. Axial location (Z): A) H = 5 m, B) H = 10 m, C) H = 15 m, D) H = 20 m, E) H = 25 m.
Figure 31 – The blade angle graph vs. Radial location (R): A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

| Journal (Location) | Impact Factor |
|--------------------|---------------|
| ISRA (India)       | 3.117         |
| ISI (Dubai, UAE)   | 0.829         |
| GIF (Australia)    | 0.564         |
| JIF                | 1.500         |
| PIF (India)        | 0.912         |
| ICV (Poland)       | 3.055         |
| ESJI (KZ)          | 0.156         |
| ICV (Poland)       | 0.564         |
| PIIF (India)       | 0.390         |
| ICV (Poland)       | 3.055         |
| SIS (USA)          | 0.156         |
| ICV (Poland)       | 3.055         |
| RIHN (Russia)      | 0.290         |
| ESJI (KZ)          | 1.500         |
| SJIF (Morocco)     | 5.667         |

Figure 32 – The theta graph vs. M-prime position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
ISRA (India) = 3.117  SIS (USA) = 0.912  ICV (Poland) = 6.630
ISI (Dubai, UAE) = 0.829  РННІ (Russia) = 0.156  PIF (India) = 1.940
GIF (Australia) = 0.564  ESJI (KZ) = 5.015  IBI (India) = 4.260
JIF = 1.500  SJIF (Morocco) = 5.667

**Figure 33** – The theta graph vs. Meridional position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

ISRA (India) = 3.117   SIS (USA) = 0.912   ICV (Poland) = 6.630
ISI (Dubai, UAE) = 0.829   РНН (Russia) = 0.156   PIF (India) = 1.940
GIF (Australia) = 0.564   ESJI (KZ) = 5.015   IBI (India) = 4.260
JIF = 1.500   SJIF (Morocco) = 5.667

Philadelphia, USA

Figure 34 – The theta graph vs. Axial location (Z): A) $H = 5\text{ m}$, B) $H = 10\text{ m}$, C) $H = 15\text{ m}$, D) $H = 20\text{ m}$, E) $H = 25\text{ m}$.
Impact Factor:

| Journal       | Impact Factor |
|---------------|---------------|
| ISRA (India)  | 3.117         |
| ISI (Dubai, UAE) | 0.829        |
| GIF (Australia) | 0.564         |
| JIF           | 1.500         |
| SIS (USA)     | 0.912         |
| GIF (Dubai, UAE) | 0.829        |
| GIF (Australia) | 0.564         |
| JIF           | 1.500         |
| ICV (Poland)  | 6.630         |
| PIIH (Russia) | 0.156         |
| ESJI (KZ)     | 5.015         |
| IBI (India)   | 4.260         |
| PIIF (India)  | 1.940         |
| SJIF (Morocco) | 5.667        |

Figure 35 – The theta graph vs. Radial location (R): A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 36 – The beta graph vs. M-prime position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

| Journal                | Impact Factor |
|------------------------|---------------|
| ISRA (India)           | 3.117         |
| SIS (USA)              | 0.912         |
| ICV (Poland)           | 6.630         |
| ISI (Dubai, UAE)       | 0.829         |
| PII H (Russia)         | 0.156         |
| PIF (India)            | 1.940         |
| GIF (Australia)        | 0.564         |
| ESJI (KZ)              | 5.015         |
| IBI (India)            | 4.260         |
| JIF                    | 1.500         |
| SIF (Morocco)          | 5.667         |
| ICV (Poland)           | 6.630         |
| PIF (India)            | 1.940         |
| GIF (Australia)        | 0.564         |
| ESJI (KZ)              | 5.015         |
| IBI (India)            | 4.260         |
| JIF                    | 1.500         |
| SIF (Morocco)          | 5.667         |

Figure 37 – The beta graph vs. Meridional position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
| Source          | Impact Factor |
|-----------------|---------------|
| ISRA (India)    | 3.117         |
| ISI (Dubai, UAE)| 0.829         |
| GIF (Australia) | 0.564         |
| JIF             | 1.500         |
| ICV (Poland)    | 6.630         |
| PII (Russia)    | 0.156         |
| ESJI (KZ)       | 5.015         |
| IBI (India)     | 4.260         |
| PIF (India)     | 1.940         |
| SJIF (Morocco)  | 5.667         |

Figure 38 – The beta graph vs. Axial location (Z): A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

| Journal                | Impact Factor |
|------------------------|---------------|
| ISRA (India)           | 3.117         |
| ISI (Dubai, UAE)       | 0.829         |
| GIF (Australia)        | 0.564         |
| JIF                    | 1.500         |
| ICV (Poland)           | 6.630         |
| PIIHII (Russia)        | 0.156         |
| ESJI (KZ)              | 5.015         |
| PIF (India)            | 1.940         |
| IBI (India)            | 4.260         |
| SJIF (Morocco)         | 5.667         |

Figure 39 – The beta graph vs. Radial location ($R$): A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 40 – The beta vs. theta graph: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 41 – The blade thickness graph vs. M-prime position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 42 – The blade thickness graph vs. Meridional position: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 43 – The blade thickness graph – % camber vs. % camber length: A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
| Journal                | Impact Factor |
|-----------------------|---------------|
| ISRA (India)          | 3.117         |
| SIS (USA)             | 0.912         |
| ICV (Poland)          | 6.630         |
| ISI (Dubai, UAE)      | 0.829         |
| РННЦ (Russia)         | 0.156         |
| PIF (India)           | 1.940         |
| GIF (Australia)       | 0.564         |
| ESJI (KZ)             | 5.015         |
| IBI (India)           | 4.260         |
| JIF                   | 1.500         |
| SJIF (Morocco)        | 5.667         |

**Impact Factor:**

**Figure 44 – The blade thickness graph vs. Axial location (Z):**

A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Figure 45 – The blade thickness graph vs. Radial location (R): A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.
Impact Factor:

|                  | ISRA (India) | SIS (USA) | ICV (Poland) | ISI (Dubai, UAE) | PHHI (Russia) | PIF (India) | GIF (Australia) | ESJI (KZ) | JIF | SIS (USA) | RIHNC (Russia) | ESJI (KZ) | SJIF (Morocco) |
|------------------|-------------|-----------|--------------|------------------|---------------|-------------|----------------|-----------|-----|-----------|----------------|-----------|----------------|
|                  | 3.117       | 0.912     | 6.630        | 0.829            | 0.156         | 1.940       | 0.564          | 5.015     | 1.500 | 0.912     | 0.156          | 5.667     |

The dependencies of the impellers blades thickness from M-Prime, M, % camber length (the current thickness graph with the vertical axis displaying the blade thickness as the percent of the total camber length and the horizontal axis displaying location as the percent of the total camber length), Z and R are calculated in the Fig. 41 – 45. These graphs are an addition to the color contours of normal thickness of the impellers blades.

The three-dimensional models of the impellers blades at the different pump heads (the Fig. 46) were built in the Model module of the Ansys Workbench software environment. The transparent volume is the created area for the calculation. The dimensions of the leading edge of the blade are presented in a foreground of the created area; the dimensions of the trailing edge of the blade are presented in a background of the created area.

![Blade Thickness Graphs](image)

**Figure 46 – The three-dimensional model of the impeller blade:** A) $H = 5$ m, B) $H = 10$ m, C) $H = 15$ m, D) $H = 20$ m, E) $H = 25$ m.

**Results and discussion**

The calculated values of the operating and geometric parameters of the impellers at the different pump heads values are presented in the summary table 3. The parameters of specific speed determine a geometric shape of the pump. $\Omega_s$ is the non-dimensional coefficient of specific speed. A type of the pump impeller is determined by the value of this coefficient. It is necessary to choose the mixed flow impeller at the pump head is 5 – 15 m. The radial impeller is selected at the pump head more than 20 m. $Ns$ and $nq$ are equivalent forms of $\Omega_s$. These
The calculated operating and geometrical parameters of the impellers/pump.

| Overall performance | Parameter          | Ωs | Ns | nq | Nss | Power, kW | Head coeff | Flow coeff | Ks | NPSHr, m | Diff ratio |
|---------------------|-------------------|----|----|----|-----|-----------|------------|------------|----|---------|------------|
| 5                   |                   | 2.48 | 6789 | 131.5 | 3.15 | 5.6 | 0.289 | 0.239 | 0.87 | 3.64 | 0.088 |
| 10                  |                   | 1.48 | 4037 | 78.2 | 3.15 | 10.5 | 0.392 | 0.134 | 0.897 | 3.64 | 0.121 |
| 15                  |                   | 1.09 | 2978 | 57.7 | 3.15 | 15.7 | 0.453 | 0.085 | 0.953 | 3.64 | 0.101 |
| 20                  |                   | 0.88 | 2400 | 46.5 | 3.15 | 20.9 | 0.455 | 0.059 | 0.996 | 3.64 | 0.073 |
| 25                  |                   | 0.74 | 2030 | 39.3 | 3.15 | 26.2 | 0.467 | 0.044 | 1.028 | 3.64 | 0.049 |

| Impeller inlet      | Parameter          | D1, mm | Cu1, m/s | Cm1, m/s | U1, m/s | W1, m/s | β1, deg | β2, deg | Inc, deg | Dh, mm | De, mm | Thk, mm |
|---------------------|-------------------|--------|----------|----------|----------|---------|-------|--------|---------|--------|--------|--------|
| 5                   |                   | 62.3 | 0 | 3.69 | 4.9 | 6.13 | 42.65 | 37.01 | 5.65 | 25.6 | 172.6 | 5 |
| 10                  |                   | 118.4 | 0 | 4.1 | 9.3 | 10.16 | 25.88 | 23.8 | 2.08 | 31.6 | 172.6 | 6 |
| 15                  |                   | 174.4 | 0 | 4.51 | 13.7 | 14.42 | 18.23 | 18.23 | 0 | 36.1 | 172.6 | 7 |
| 20                  |                   | 120.3 | 0 | 4.27 | 9.45 | 10.37 | 26.41 | 24.3 | 2.11 | 39.7 | 172.6 | 7.9 |
| 25                  |                   | 173.9 | 0 | 4.69 | 13.66 | 14.44 | 18.97 | 18.97 | 0 | 42.8 | 172.6 | 8.8 |

| Impeller exit       | Parameter          | D2, mm | B2, mm | Lean, deg | β2, deg | W2, m/s | α2, deg | C2, m/s | Wslip/U2 | U2, m/s | Cu2, m/s |
|---------------------|-------------------|--------|--------|-----------|--------|---------|---------|---------|----------|---------|----------|
| 5                   |                   | 166 | 71.5 | 0 | 19.37 | 9.26 | 35.53 | 5.28 | 0.1 | 13.04 | 4.3 |
| 10                  |                   | 201.3 | 68.6 | 0 | 16.84 | 9.11 | 20.42 | 7.57 | 0.15 | 15.81 | 7.09 |
| 15                  |                   | 234.2 | 57.3 | 0 | 16.35 | 9.64 | 16.53 | 9.54 | 0.15 | 18.4 | 9.14 |
| 20                  |                   | 264.5 | 47.8 | 0 | 16.12 | 10.39 | 14.95 | 11.17 | 0.15 | 20.78 | 10.8 |
| 25                  |                   | 291.7 | 40.9 | 0 | 15.96 | 11.11 | 14.01 | 12.61 | 0.14 | 22.91 | 12.24 |

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ISRA (India) = 3.117  SIS (USA) = 0.912  ICV (Poland) = 6.630
ISI (Dubai, UAE) = 0.829  PIIHI (Russia) = 0.156  PIF (India) = 1.940
GIF (Australia) = 0.564  ESJI (KZ) = 5.015  IBI (India) = 4.260
JIF = 1.500  SJIF (Morocco) = 5.667

Suction specific speed Nss characterizes intensity of the pump cavitation. The calculated values of Nss were 3.15. This indicates about good cavitation characteristic of the pump. The shaft power is increased in average by 5.2 kW at increasing of the pump head by 5 m. The head coefficient ψ has characteristic of energy transfer measure to fluid. Maximum difference of energy transfer to fluid was determined at the small values of the pump head. Changing determination of flow rate through the pump is carried out by the value of the flow coefficient. The flow coefficient is 0.239 at the pump head of 5 m, the flow coefficient is 0.044 at the pump head of 25 m. The stability factor Ks determines stable characteristic of the pump performance. Unstable characteristic of the pump performance is observed at head of 5 and 10 m (Ks < 0.9). Net positive suction head required (NPSHr) for the pump performance provides reduction of noise and damage due to cavitation. NPSHr for all considered pumps is 3.64 m. The diffusion ratio determines stable of head-flow curve. Maximum stable was determined at the diffusion ratio is 0.049; minimum stable was determined at the diffusion ratio is 0.121.

The hub diameter (Dh) changes by 17.2 mm at increasing of the pump head by 20 m and the eye diameter (De) does not change (172.6 mm). The blades thickness of the impellers is increased in the range from 5 to 8.8 mm with increasing of the pump head. The values of the diameter (D1), tangential velocity (Cu1), meridional velocity (Cm1), the blade speed (U1), flow relative velocity (W1), the blade angle (β1), relative flow angle (β2) and incidence (Inc) were calculated in the sections of the hub, the mean line and the shroud of the impellers. Incidence is calculated as difference of the angles of β1 and β2. Increasing of the D1 parameter at the hub and decreasing at the shroud is required with increasing of the pump head. Tangential velocity was not taken into account. Maximum meridional velocity is achieved at the impeller shroud. The blade speed of
the impeller increases in the sections of the hub and the mean line. Flow relative velocity of fluid at the impeller inlet varies from 6.13 to 14.88 m/s. Maximum changing of flow relative velocity of fluid is determined at the impeller hub. The blade angle of the impeller decreases at the hub, the relative flow angle increases at the mean line. The values of $\beta_I$ and $\beta_I$ are equal at the shroud.

The calculated parameters at the impeller trailing edge were written in the title **Impeller exit** (the table 3). The tip diameter ($D_2$) changes in average by 31 mm at changing of the pump head by 5 m. Maximum changing of the tip width of the impeller ($B_2$) is observed at the pump head of 10 – 20 m. The calculated value of the lean angle was 0 degrees according to the results of five researches. The ratios of $U_1$ to tip speed at the impeller outlet ($U_2$) are from 0.375 to 0.594. Flow relative velocity at the impeller outlet ($W_2$) is higher than $W_1$ at the hub and lower than at the mean line and the shroud. Relative flow angle ($\beta_2$) at the impeller outlet is less than at the inlet. The absolute flow angle ($\alpha_2$) is more than $\beta_2$ at the pump head values of 5 – 15 m. Flow tangential velocity ($Cu_2$) at the impeller outlet increases in the range of 4.3 – 12.24 m/s, i.e. increases in 3 times at increasing of the pump head in 5 times. The values of flow absolute velocity ($C_2$) at the impeller outlet were determined in the range of 5.28 – 12.61 m/s. The slip factor ($W_{slip}/U_2$) characterizes the deviation degree of fluid flow from the impeller blade.

The minimum degree of deviation of fluid flow is calculated at the pump head of 5 m and the corresponding geometry of the impeller blade.

**Conclusion**

Based on the performed analysis of the designed geometry of the impellers in conditions of changing of the pump head, it is possible to draw the following conclusions:

1. The impeller blades with the larger profile curvature should be made at the pump head of more than 20 m.
2. Required performance of the pump (by conditions of the performed experiments) is provided by the mixed flow impellers at the pump head of up to 15 m and the radial impellers at the pump head of more than 20 m.
3. The surfaces cavitation of the impellers occurs with the same intensity at the different pump heads and geometric characteristics of the blades.
4. Stable characteristic of the pump is observed at operation of the radial impellers with the calculated geometry. The calculated geometry of the impeller at the pump head of less than 10 m leads to unstable characteristic of the pump.
5. Calculated deviation of fluid flow from the impeller blade at the pump heads of 10 – 20 m is more by 5% than at the pump head of 5 m.

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