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DATA ACQUISITION SYSTEM FOR VELOCITY PATTERN INVESTIGATION OF A STREAM IN CENTRIFUGAL PUMP SUCTION DUCT****

SUMMARY

In the thesis are presented structure and potential measuring stand realized on need of investigation of influence of the additional angular momentum of a stream under suction on formation the field of velocity in space before the impeller of the impeller pump. Measurement stand will make possible the qualification of influence of parameters additional stream liquid, introduced to space before impeller, on quality of inflow of stream on stockade of blades.

Keywords: *measuring systems, profiles of velocity, software*

UKŁAD POMIAROWY DO BADANIA PÓL PRĘDKOŚCI STRUGI W PRZESTRZENI PRZEDWIRNIKOWEJ POMPY ODŚRODKOWEJ

W pracy przedstawiono budowę i możliwości stanowiska pomiarowego zrealizowanego na potrzeby badania wpływu dodatkowego krętu strugi na kształtowanie pola prędkości w części ssawnej rurociągu tuż przed wirnikiem pompy wirowej. Badania stanowiskowe powinny umożliwić określenie wpływu parametrów dodatkowej strugi płynu, wprowadzanej do przestrzeni przedwirnikowej, na jakość napływu strumienia na palisadę łopatek.

Słowa kluczowe: *system pomiarowy, pole prędkości*

1. DESCRIPTION OF THE LABORATORY STAND

The view of laboratory stand is shown in Figure 1. It has been designed and developed in such a way that it keeps water pumping in open circulation. The set of equalising water tanks 1 together with suction pipe 2 has been used to eliminate influence of stream perturbation appeared in return line 9 on flow type in suction duct 3 of pump 4. An investigated centrifugal pump 4 is driven by three-phase motor 5. A variable-frequency drive 7 has been fitted on the laboratory stand to make available continuous changes of electric motor rotation speed, thereby volumetric efficiency of pump 4. Volumetric flow rate in suction duct of centrifugal pump is measured by flowmeter 6. Water is pumped further out of the valve 8 to set of water tanks through return pipe 9. Write here in a described system the water circulation starts up again.

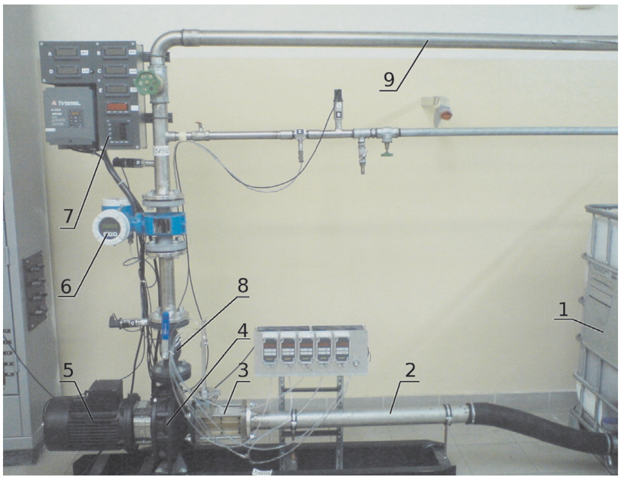

Fig. 1. View of laboratory stand: 1 – set of equalising water tanks, 2 – suction pipe, 3 – suction duct with measuring head, 4 – investigated centrifugal pump, 5 - three-phase electric motor, 6 – flowmeter, 7 – electric motor rotational speed control system, 8 – cut off valve, 9 – return pipe

2. MEASURING SYSTEM DESCRIPTION

Laboratory stand is equipped with several control and measuring systems. The most important control system is one used for rotation speed adjusting of three-phase electrical motor which drive centrifugal pump. The most important in this control system is variable-frequency drive which allows adjusting appropriate frequency and amplitude of current supplying each coil of three-phase electrical motor. During investigation only the frequency of the electrical power supplied to the motor has been adjusted for controlling their rotational speed. Thanks to embedded microcontroller rotational speed adjustment could be achieved by choosing appropriate value by control desk.

Rotational speed of pump has decisive impact on fluid flow rate measured at the flow out port. Measurement of real fluid flow rate is realising by means of vortex flowmeter. This type of measurement device is characterised by wide range of flow rate.

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For determining velocity pattern of a water stream in centrifugal pump suction duct measurement system with five point sphere probe has been developed. This probe has been installed in specially designed measuring pipe segment in a way to make available position changes of the probe perpendicularly and along to the axis of the pump suction duct. Such configuration makes it possible to determine spatial velocity pattern of a fluid stream which is necessary to qualitative and quantitative determination of pump rotational speed influence into fluid spin stream induced in the pump suction duct.

A schematic of measuring system for determining fluid steam velocity vector in pump suction duct is presented in the Figure 2. Measuring points of sphere probe 4 are connected with pressure transducers 3, which make available measurement of dynamic pressures changes p_1, p_2, p_4 and p_5. Additionally differential pressure p_3–p_2 is measured as well. All pressures are logged by means of data acquisition system consisted of computer 1 connected with measuring card 2 via USB cable. Thanks to application software operating measuring card it is possible both pressure signal logging and stream velocity vector determining in spherical and cylindrical coordinates. It simplifies hard measuring procedure what is most important especially in case of repetition necessity for successive measuring points.

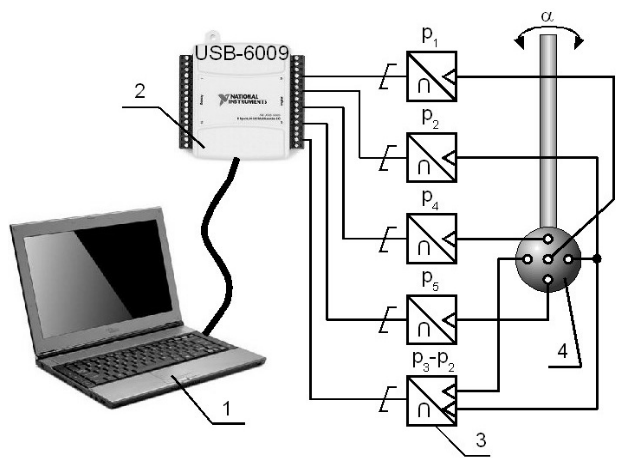

Fig. 2. A schematic of measuring system for determining fluid steam velocity vector in pump suction duct: 1 – measuring computer, 2 – data acquisition card, 3 – transducers for measuring pressures p_1, p_2, p_4 and p_5 as well as differential pressure p_{32}, 4 – five point sphere probe

3. SOFTWARE

Introduction to LabVIEW

Many technological processes require individual solution creation in range of measurement, identification, control and management. Especially it concerns scientific laboratories, where researches on unique laboratory stands and wide range of prototype facilities are provided. LabVIEW software package was created with a view to engineers designing such systems. Reach algorithmic routine library connected with processing, presentation and storage of measurement data makes this software free in creating of any sophisticated measurement, diagnosis or measurement and control facilities which fit to the connected process. Developed software base on LabVIEW is usually called virtual instrument.

Prepared previously virtual instrument could be installed on any hardware platform that becomes next upside of the software which was used in our project. It could be PC computer, laptop or palmtop equipped with data acquisition card. Usually for industry's purpose specially designed computers or controllers e.g. Programmable Automation Controllers (PAC) working under real-time system are being applied to.

Creation of applications which solves typical acquisition problems is relatively simple using LabVieW software. Programmers prepare several templates which allow automatic code generation after carrying through appropriate questionnaire leading to solve over 90% of problems could be met in engineering praxis. In case of atypical problems have to be solved LabView entirely make their features available to the engineers. Programming is being in progress in graphics environment where ideology known form C language was maintained.

Basic tasks of software

Main goal established during software application was to simplify research task as well as logging all data obtained during acquisition necessary for further analysis. Research task has been realised in six steps described below:

Step 1 – adjusting rotational speed of electric motor driving pump,

Step 2 – position location of a sphere probe in appropriate measuring point to achieve pressure difference p_3–p_2 equal zero measured and indicated by differential pressure transducer,

Step 3 – p_1, p_2, p_4, and p_5 pressure value measuring as well as coefficient K_φ and angle φ value assignment,

Step 4 – angle $\Delta\alpha$ correction value assignment as well as coefficient values K_1, K_2, K_3 and K_5,

Step 5 – real value of angle α assignment,

Step 6 – value of dynamic pressure p_d and velocity c assignment.

MyFlow.exe program written in LabVIEW is realising main goal assumed by designers. Thanks to this program automation of laboratory procedure for steps 3, 4, 5 and 6 was realised. Data acquisition was divided on two stages. First stage which realise first and second step of the research task is called "data input" in turn second stage called "acquisition" amount to log of most important data connected with measuring and assuming values in step 3, 4, 5 and 6 of the research task.

Fist stage finishes after fill in to program following data:

N – electric motor rotary speed driving pump [1/min],

Q – flow rate measured in main branch of pipeline [dm^3/min],

q_1 – flow rate measured in lateral branch of pipeline [dm^3/min],

x – relative axial coordinate of sphere probe in suction duct [mm],

z – relative radial coordinate of sphere probe in suction duct [mm].

Next stage leads to laborious calculation based on measured values of pressures p_1, p_2, p_4 and p_5 corresponding to the sphere probe measuring points. At the beginning based on equation (1) value of coefficient K_φ was calculated.

$$K_\varphi = \frac{(p_5 - p_4)}{(p_1 - p_2)} \tag{1}$$

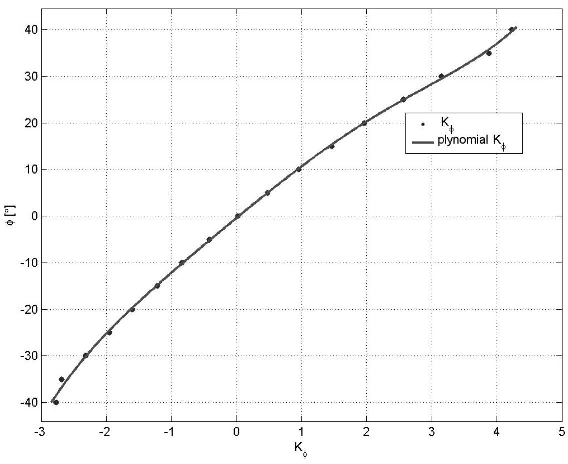

Fig. 3. Characteristic curve of angle φ in function of coefficient K_φ

Further calculations require knowledge of characteristic curves distinguished during calibration process and delivered by producer of sphere probe. First characteristic curve describing an angle φ changes in function of coefficient K_φ is shown in the Figure 3. Assigned angle is one of the spherical coordinates describing velocity vector of fluid stream. Another characteristic curve shown in the Figure 4 present set of curve describing dependencies between dimensionless coefficient K_i and angle φ. Thanks to knowledge of such angle value it is possible to assign appropriate coefficients K_i value necessary for calculating value of dynamic pressure p_d.

Dynamic pressure p_d value is calculated using equation (2).

$$p_d = \frac{(p_i - p_j)}{(K_i - K_j)} \tag{2}$$

where i and j are the numbers of sphere probe measuring points chosen in such a way to maximise value of numerator and denominator. This treatment allows us to minimize an error as a consequence of measuring method.

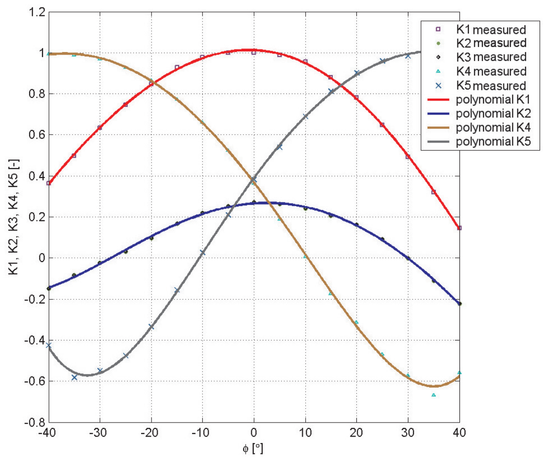

Fig. 4. Set of coefficients K_i characteristic curves in function of angle φ

If value of dynamic pressure is known we can calculate length of velocity c vector taking advantages from equation (3).

$$c = \sqrt{\frac{2 \cdot p_d}{\rho}} \tag{3}$$

Real value of angle α determining longitude of velocity vector c in cylindrical coordinates depend on determined value of angle φ. It has been defined by last characteristic curve (Fig. 5) delivered by the producer of sphere probe. Using this characteristic we can read out value of correction error Δα which has to be added to angle α value measured on circular protractor fixed to the measuring saddle root.

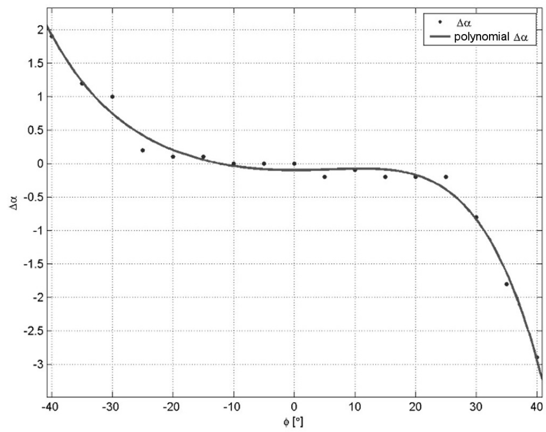

Fig. 5. Characteristic curve of correction angle α in function of angle φ

Additionally value of fluid stream velocity vector coordinates have been converted into cylindrical coordinates.

Instead of characteristic curve described above interpolation polynomial written as equations (4)–(9) and (10) have been used in our research task.

$$\varphi = -0.0036 \cdot K_\varphi^4 + 0.08 \cdot K_\varphi^3 - 0.7001 \cdot K_\varphi^2 + \\ +11.078 \cdot K_\varphi - 0.0668 \tag{4}$$

$$K1 = 5\cdot 10^{-10}\cdot\varphi^5 + 3\cdot 10^{-8}\cdot\varphi^4 - 2\cdot 10^{-6}\cdot\varphi^3 - -0.0005\cdot\varphi^2 - 0.001\cdot\varphi + 1.0123 \quad (5)$$

$$K2 = -3\cdot 10^{-10}\cdot\varphi^5 + 4\cdot 10^{-8}\cdot\varphi^4 - 10^{-6}\cdot\varphi^3 - -0.0004\cdot\varphi^2 + 0.0019\cdot\varphi + 0.2656 \quad (6)$$

$$K3 = K2 \quad (7)$$

$$K4 = 10^{-9}\cdot\varphi^5 + 10^{-7}\cdot\varphi^4 + 6\cdot 10^{-6}\cdot\varphi^3 - -0.0003\cdot\varphi^2 - 0.0327\cdot\varphi + 0.3665 \quad (8)$$

$$K5 = -2\cdot 10^{-9}\cdot\varphi^5 + 2\cdot 10^{-7}\cdot\varphi^4 - 8\cdot 10^{-6}\cdot\varphi^3 - -0.0003\cdot\varphi^2 + 0.034\cdot\varphi + 0.3895 \quad (9)$$

$$\Delta\alpha = -1.253\cdot 10^{-8}\cdot\varphi^5 - 4.541\cdot 10^{-7}\cdot\varphi^4 - -1.799\cdot 10^{-5}\cdot\varphi^3 + 0.000467\cdot\varphi^2 - -0.0001284\cdot\varphi - 0.09907 \quad (10)$$

All adduce calculations are realised automatically by software. User task is only boiling down to fill in such data as pump working parameters, coordinates of sphere probe, other parameters read from instruments and saving all data to previously prepared file.

4. THE MEASUREMENT RESULTS

The above presented measuring stand has allowed to define profiles of velocity in the suction pipeline just in front of the impeller of the impeller pump. The research have been conducted for the beforehand stated parameters of the pump at work which are shown in the Table 1.

The collected measurement data enable to define components of the vector of velocity at each of the examined points of the researched profile. Thanks to that spatial layouts of vectors of fluid velocity can be constructed in the 3-dimensional graphics. It is relevant as the attempt of interpretation of the layouts which are presented only in the form of isometry may be difficult. For example the Figure 6 shows the profile of velocity for the examined pump working with the velocity of 1250 revolutions per minute and with changing efficiency.

Table 1

The selected range of the conducted measurements

n = 1050 [rev/min]	*n* = 1250 [rev/min]	*n* = 1450 [rev/min]	*n* = 1550 [rev/min]
Q = 50 [l/min]	*Q* = 50 [l/min]	*Q* = 50 [l/min]	*Q* = 50 [l/min]
Q = 150 [l/min]	*Q* = 150 [l/min]	*Q* = 150 [l/min]	*Q* = 150 [l/min]
Q = 250 [l/min]	*Q* = 250 [l/min]	*Q* = 250 [l/min]	*Q* = 250 [l/min]
Q = 340 [l/min]	*Q* = 350 [l/min]	*Q* = 350 [l/min]	*Q* = 340 [l/min]

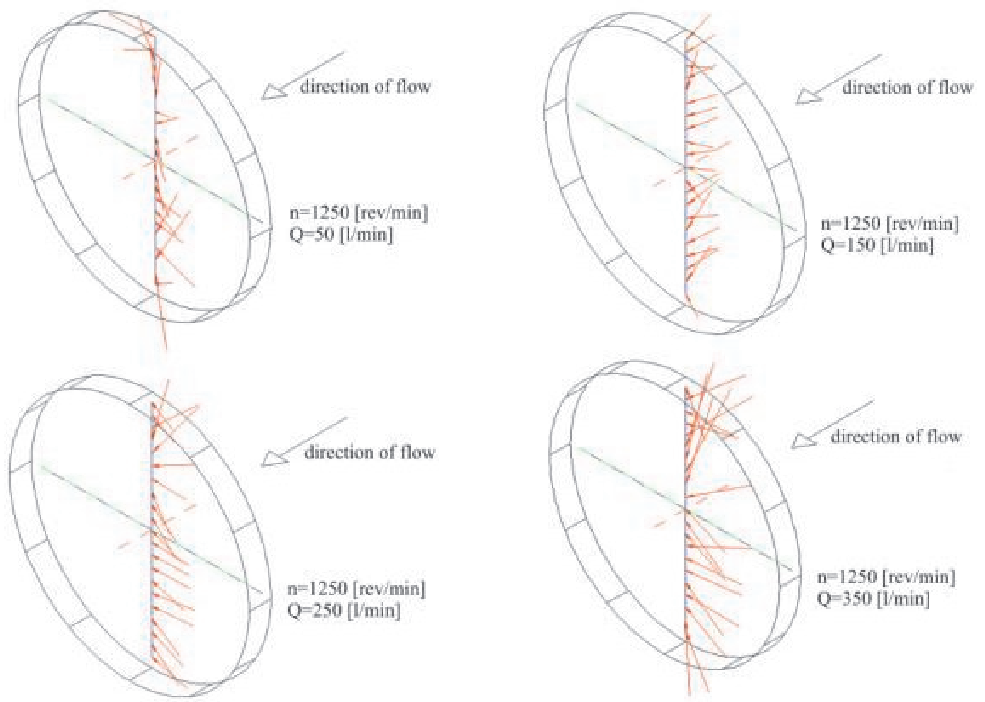

Fig 6. The vectors of fluid velocity in the suction area in front of the impeller pump's rotor

Following the above observations an analysis of the presented fields of velocity is difficult or even impossible. Therefore the use of layouts of velocity vectors in the 3-dimensional graphic form is so important for further research over the influence of additional prerotation on characteristics of the impeller pump.

While having at our disposal layouts of velocity in the 3-dimensional graphic form we have a possibility of free monitoring of their respective position as well as of making unrestricted sets of components. Such a possibility is shown in the Figure 7 which presents the layout of the vectors of velocity for 1250 revolutions per minute and the flow of 50 l/min.

Obviously besides the data in the graphic form we possess numerical data which enable an accurate interpretation not only a qualitative one but quantitative one as well. Table 2 presents an extract of exemplary values calculated for a pump working by n =1450 rev/min and v = 50 l/min.

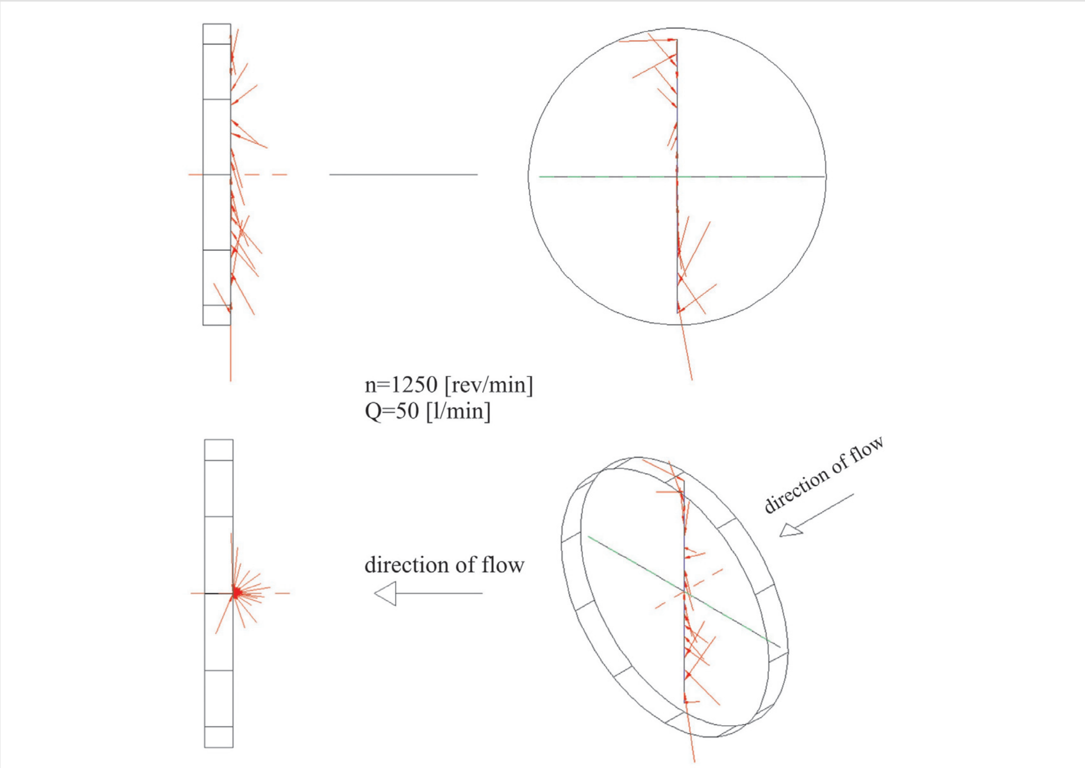

Fig 7. The layout of the fluid velocity in the suction area in front of the rotor of the impeller pump by (n = 1250 rev/min and v = 50 l/min)

Table 2

The calculation results of a pump working by n = 1450 rev/min and v = 50 l/min

Lp.	n [obr/min]	Q [l/min]	q1 [l/min]	x [mm]	z [mm]	r	pd [Pa]	pst [Pa]	pc [Pa]	v [m/s]	fi [st]	alfa [st]	c_z [m/s]	c_{xy} [m/s]	p3 - p2 [Pa]	p1 [Pa]	p2 [Pa]	p4 [Pa]	p5 [Pa]
1	1450	50	0	1	0	30	878,22	2719,44	4197,91	1,33	26,15	-91,52	1,13	0,69	-11,19	3860,58	3364,50	2256,12	3597,22
2	1450	50	0	1	3	27	458,71	2929,50	3388,21	0,96	5,83	-83,74	-0,42	0,86	-33,25	3383,20	3050,11	1784,18	1967,51
3	1450	50	0	1	6	24	551,55	2399,70	2951,25	1,05	2,25	-76,08	0,82	-0,66	-26,08	2955,39	2547,43	1615,40	1701,67
4	1450	50	0	1	9	21	603,11	1762,25	2365,36	1,10	1,33	-67,59	1,07	0,26	-0,55	2371,45	1923,53	1543,91	1600,74
5	1450	50	0	1	12	18	507,10	1443,32	1950,42	1,01	2,41	-57,28	0,67	-0,75	-21,40	1953,94	1579,14	1416,87	1501,90
6	1450	50	0	1	15	15	480,73	1233,13	1713,86	0,98	3,02	-43,17	0,12	-0,97	2,91	1716,09	1361,80	1375,64	1476,23
7	1450	50	0	1	18	12	431,47	1161,08	1592,55	0,93	4,80	-26,05	-0,93	0,09	-37,45	1590,71	1275,59	1321,08	1463,50
8	1450	50	0	1	21	9	412,04	1192,26	1604,30	0,91	5,97	-15,24	-0,28	0,86	-73,33	1599,41	1300,43	1278,75	1447,17
9	1450	50	0	1	24	6	469,76	1120,39	1590,15	0,97	5,93	-6,74	-0,33	0,91	-19,08	1584,69	1243,77	1241,02	1431,96
10	1450	50	0	1	27	3	665,48	1090,38	1755,86	1,15	3,16	-3,27	-0,02	-1,15	10,79	1758,57	1268,45	1307,68	1453,13
11	1450	50	0	1	30	0	716,96	1022,96	1739,93	1,20	2,32	-0,08	0,88	-0,81	-3,11	1745,14	1215,00	1355,92	1471,52
12	1450	50	0	1	33	-3	652,72	1018,31	1671,02	1,14	3,64	1,94	-0,55	-1,00	7,28	1672,29	1192,70	1330,00	1493,85
13	1450	50	0	1	36	-6	717,98	968,45	1686,43	1,20	2,96	5,13	0,21	-1,18	-2,33	1689,94	1160,65	1354,96	1502,23
14	1450	50	0	1	39	-9	676,31	974,37	1650,68	1,16	2,79	9,33	0,40	-1,09	5,50	1654,45	1155,47	1388,55	1519,40
15	1450	50	0	1	42	-12	661,35	980,74	1642,09	1,15	2,71	14,33	0,48	-1,04	-32,08	1645,98	1157,85	1423,04	1547,30
16	1450	50	0	1	45	-15	657,05	1002,89	1659,94	1,15	0,99	24,71	0,96	0,63	-20,61	1667,04	1178,38	1506,02	1553,00
17	1450	50	0	1	48	-18	834,66	931,01	1765,67	1,29	-1,69	38,09	-1,28	-0,16	3,90	1776,16	1149,06	1705,57	1614,40
18	1450	50	0	1	51	-21	1275,22	849,07	2124,29	1,60	-2,23	56,28	-1,27	-0,97	-13,52	2139,68	1179,86	2000,69	1815,84
19	1450	50	0	1	54	-24	1887,36	854,91	2742,27	1,94	-0,08	74,80	-0,15	1,94	-28,43	2765,63	1355,91	2360,23	2358,80
20	1450	50	0	1	57	-27	2117,52	1274,47	3391,99	2,06	2,45	91,33	1,32	-1,58	-12,91	3406,46	1841,63	2420,00	2780,21
21	1450	50	0	1	60	-30	801,28	1932,01	4087,28	1,27	30,27	112,94	-1,15	0,52	-14,76	3673,61	3254,71	1433,31	2764,52

In order to appropriately interprete the results obtained thanks to the constructed stand the thorough knowledge of the algorithm for collecting of measurement results is indispensable and afterwards their processing into physical values which describe the fluid flow at the intersection being analysed. Thanks to the ability, following the completion of further research with application of the forced prerotation, it will be possible to provide a thorough comparison and evaluation of the influence of the application of the new method of shaping the fluid stream in the suction area of the impeller pump on the characteristics of its work.

5. CONCLUSIONS

The software created for the use of the discussed research largely simplifies research procedures as well as it makes easier to record and file the measured quantities which are the basis for an analysis of the experiment results. Indispensable calculations are done automatically by the program which enables easy construction of sophisticated spatial layouts of the velocity of the sucked stream near the rotating grid of blades. The detailed analysis of the measured quantities collected both in the graphic form and numerical one should help to estimate the influence of the natural prerotation as well as the additional angular momentum of the sucked stream on the way the incoming fluid stream is shaped.

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