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HydroHillChart – Francis module. Software used to Calculate the Hill Chart of the Francis Hydraulic Turbines

The paper presents the ***Hydro Hill Chart*** *- Francis module application, used to calculate the hill chart of the Pelton, Francis and Kaplan hydraulic turbine models, by processing the data measured on the stand. After describing the interface and menu, the input data is graphically presented and the universal characteristic for measuring scenarios a_o=const. and n_{11}=const is calculated. Finally, the two calculated hill charts are compared through a graphical superimposition of the isolines.*

Keywords*: turbine, Francis, runner, hill chart, Python*

1. Introduction

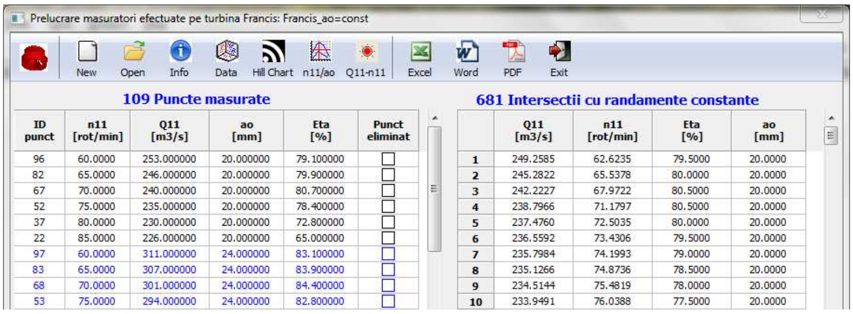
The hill chart expresses the functional dependence of the Francis turbine parameters (n_{11}, Q_{11}, a_o, η) graphically and is the instrument on which the industrial turbine is designed. This dependence arises from extensive experimental research carried out on Francis turbine models, leading to a library of optimized characteristics for the specific flows and falls of these turbines types. The test models have a complex character, because they are made in several operating conditions, high measuring accuracy and low cost compared to those made on the prototype of industrial turbines. Tests can be carried out on the industrial turbine when it is placed in service, but their reception is usually made by testing the model parameters in order to verify guaranteed parameters.

2. The HydroHillChart software

The **HydroHillChart** software [1] is a complex one used to calculate and plot the hill chart for Pelton [2], [3], Francis and Kaplan turbines. The application was developed in the Python programming language, while the mathematical tool used for interpolation is the cubic spline type function.

3. The Francis module

The **Francis turbine** option from the main menu displays a window with a specific Francis module interface, Figure 1, composed of: toolbar, measured data table called **Puncte măsurate** (in which measured data for a model runner is loaded) and the table called **Puncte de intersecție cu randament constant** (where the application stores values that result from the intersection of primary curves with constant efficiency).



ID punct	n11 [rot/min]	Q11 [m3/s]	ao [mm]	Eta [%]	Punct eliminat
96	60.0000	253.000000	20.000000	79.100000	☐
82	65.0000	246.000000	20.000000	79.900000	☐
67	70.0000	240.000000	20.000000	80.700000	☐
52	75.0000	235.000000	20.000000	78.400000	☐
37	80.0000	230.000000	20.000000	72.800000	☐
22	85.0000	226.000000	20.000000	65.000000	☐
97	60.0000	311.000000	24.000000	83.100000	☐
83	65.0000	307.000000	24.000000	83.900000	☐
68	70.0000	301.000000	24.000000	84.400000	☐
53	75.0000	294.000000	24.000000	82.800000	☐

	Q11 [m3/s]	n11 [rot/min]	Eta [%]	ao [mm]
1	249.2585	62.6235	79.5000	20.0000
2	245.2822	65.5378	80.0000	20.0000
3	242.2227	67.9722	80.5000	20.0000
4	238.7966	71.1797	80.5000	20.0000
5	237.4760	72.5035	80.0000	20.0000
6	236.5592	73.4306	79.5000	20.0000
7	235.7984	74.1993	79.0000	20.0000
8	235.1266	74.8736	78.5000	20.0000
9	234.5144	75.4819	78.0000	20.0000
10	233.9491	76.0388	77.5000	20.0000

Figura 1. The interface of **Francis** module

The Input data is taken from Excel and placed in the table called **Puncte măsurate,** by completing the following fields:

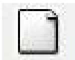
- **ID point** - represents the current number for the measured point;
- **n_{11} [rot/min]** - represents the unitary speed;
- **Q_{11} [m^3/s]** - represents the unitary flow;
- **a_o [mm]** - represents the wicked gate opening;
- **η [%]** - represents the efficiency;
- **Punct eliminat** – allows the removal of a measured point, by selecting a **Check Box.**

Because the entire turbine operating range cannot be explored through measurements, the measurements are punctually made at a constant parameter and from the parametric curve interpolation, the hill chart of the model arises. For a Francis turbine model, measurements can be performed by using the following parameters a_o=const., wicked gate opening, or n_{11}=const., unitary speed. Therefore, when reading the input data, the Francis module should be notified by the user about the measuring scenarios that were used (a_o = const. or n_{11} = const), by specifying the option when a new database is created. Although the input data fields are identical, for all measurement scenarios, graphic representations and calculation algorithms differ for the two scenarios. The resulting curves are different, but if the interpolations are sufficiently precise, what should coincide is the hill chart. Thereby, for a data set where the starting point (n_{11}, Q_{11}, a_o, η) is at the intersection of a a_o=const. range of values with a n_{11}=const. range of values, the hill chart which arises from the primary data considered to be measured at a_o=const. should overlap with the one which arises from the primary data considered to be measured at n_{11}=const.

3.1. The Francis module toolbar

The Francis module toolbar is located at the top of the window and includes control buttons marked with specific icons, figure 1, which fulfill the following functions:

- informative icon for the Francis runner, without a related function;



New

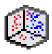
- create a new database for Francis runners; to create a new database the following information need to be completed: turbine type name, database filename, the period when the measurements took place, the person responsible for the performed measurements, additional information; the measurement values are taken from an Excel file.

Open

- opening and loading an existing database for Francis runners; after this operation, the **Puncte măsurate** table, Figure 1, will be emptied and then rewritten with the values from the selected database.

Info

- provides information about the current database; turbine type name, database filename, the period when the measurements took place, the person responsible for the performed measurements, the file from which the measured data was taken, number of measured and eliminated points, minimum and maximum values for unitary speed, unitary flow, injector needle opening and efficiency.



Data

- input data visualization in graphic form: 3D curves and $\eta = f(n_{11}, Q_{11})$ 3D surface, respectively 2D parametric curves;

Hill Chart

- calculating and plotting the hill chart for a number of specified efficiencies values;

n_{11}/a_o

- imposing a parameter (double unitary speeds n_{11} or wicked gate opening a_o) and the intersection of the characteristic $\eta = f(n_{11}, Q_{11})$ with this parameter;

Q_{11}-n_{11}

- imposing double unitary speeds n_{11} and unitary flow Q_{11}, followed by the characteristics intersection $\eta = f(n_{11}, Q_{11})$ in order to calculate the efficiency point (Q_{11}, n_{11});

Excel

- export results in an Excel file: input data and the numerical and graphical processing carried out;

Word

- graphics export in a Word file;


PDF - graphics export in a PDF file;


Exit - return to the main window of the **HydroHillChart** software.

3.2. The Graphics Toolbar

For each graph generated by the **HydroHillChart** software, at the bottom of the window, a toolbar with command buttons marked with specific icons can be found, which perform the following functions:

 **Home** - Return to initial view;

 **Back** - Back to previous view;

 **Forward** - Forward to the next view;

 **Pan** - Left click and hold to zoom, zoom in/out with the right mouse button pressed;

 **Zoom** - Enlarge selected area;

 **Subplots** - Chart configuration;

 **Save** - Save chart format: EPS; JPG, PGF, PDF; PNG, PS; RAW, SVG, TIF.

3.3. The "DATA" button

The **DATA** button enables the graphical view of the input data, according to Table 1:

Table 1. Input data view in graphical form

a_o=const. measuring scenarios	Figure	n_{11}=const. measuring scenarios	Figure
$\eta = f(n_{11}, Q_{11})$ 3D surface	2	$\eta = f(n_{11}, Q_{11})$ 3D surface	10
$a_o = f(n_{11}, Q_{11})$ 3D surface	3	$a_o = f(n_{11}, Q_{11})$ 3D surface	11
$\eta = f(n_{11}, Q_{11})$ 3D curves	4	$\eta = f(n_{11}, Q_{11})$ 3D curves	12
$a_o = f(n_{11}, Q_{11})$ 3D curves	5	$a_o = f(n_{11}, Q_{11})$ 3D curves	13
$\eta = f(n_{11})$ overlaid 2D curves	6	$\eta = f(Q_{11})$ overlaid 2D curves	14
$Q_{11} = f(n_{11})$ overlaid 2D curves	7	$a_o = f(Q_{11})$ overlaid 2D curves	15
$\eta = f(n_{11})$ şi $Q_{11} = f(n_{11})$ 2D parametric curves	8 9	$\eta = f(a_o)$ şi $Q_{11} = f(a_o)$ 2D parametric curves	16 17

Figures 8 and 16 are identical to Figures 9 and 17, with the difference being that in the first figures only the measurement points are shown and in the last figures, the interpolated points which arise from the intersection of primary curves with efficiency constant values are also represented, which are used in the calculation of the hill chart.

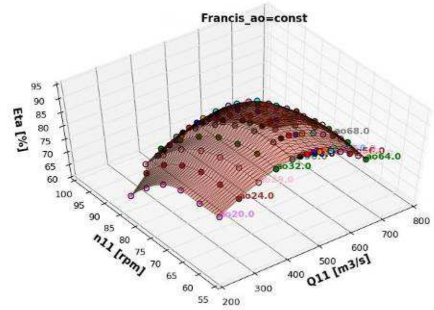


Figure 2. $\eta = f(n_{11}, Q_{11})$ 3D surface for a_o=const.

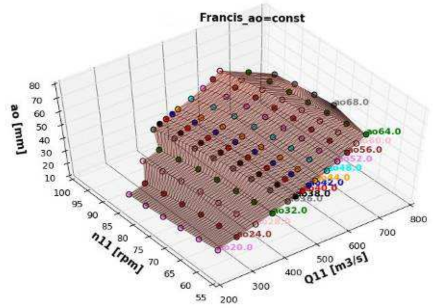


Figure 3. $a_o = f(n_{11}, Q_{11})$ 3D surface for a_o=const.

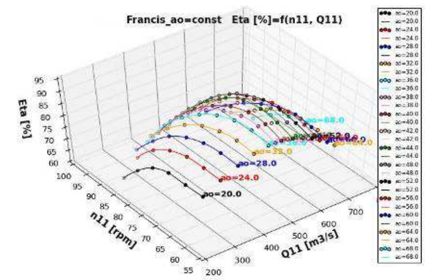


Figure 4. $\eta = f(n_{11}, Q_{11})$ 3D curves for a_o=const.

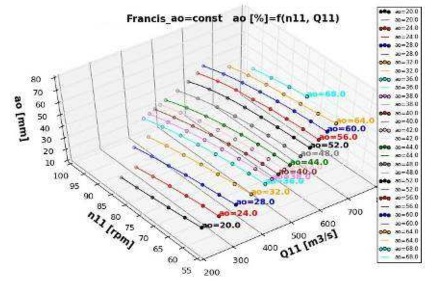


Figure 5. $a_o = f(n_{11}, Q_{11})$ 3D curves for a_o=const.

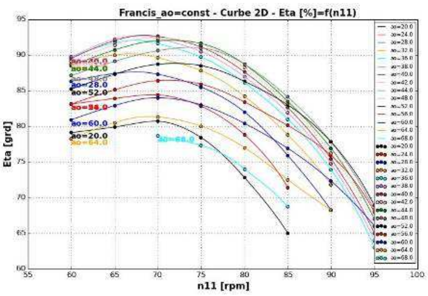


Figure 6. $\eta = f(n_{11})$ 2D curves for a_o=const.

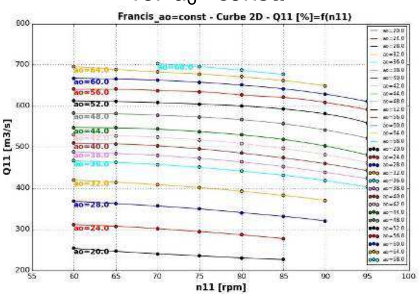


Figure 7. $Q_{11} = f(n_{11})$ 2D curves for a_o=const.

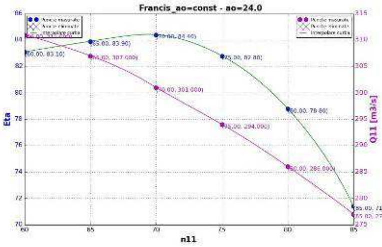


Figure 8. $\eta = f(n_{11})$ and $Q_{11} = f(n_{11})$ 2D curves for a_o=24

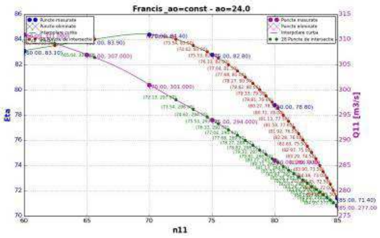


Figure 9. $\eta = f(n_{11})$ and $Q_{11} = f(n_{11})$ 2D curves with points $\eta = const$.

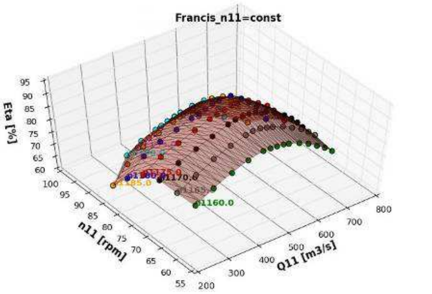


Figure 10. $\eta = f(n_{11}, Q_{11})$ 3D surface for n_{11}=const.

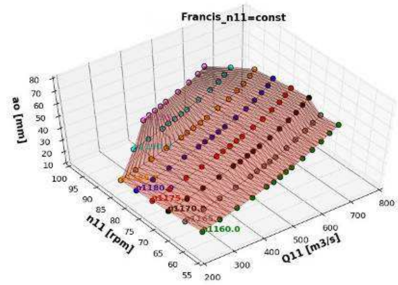


Figure 11. $a_o = f(n_{11}, Q_{11})$ 3D surface for n_{11}=const.

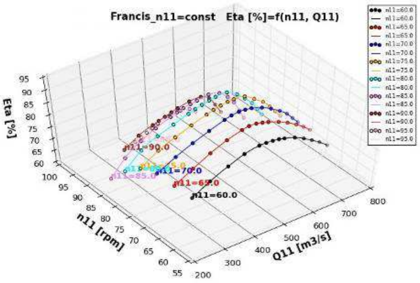


Figure 12. $\eta = f(n_{11}, Q_{11})$ 3D curves for n_{11}=const.

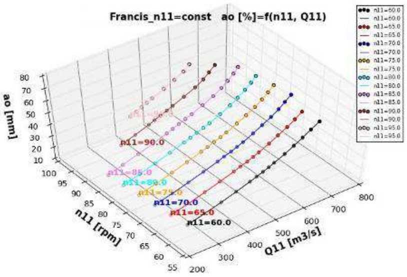


Figure 13. $a_o = f(n_{11}, Q_{11})$ 3D curves for n_{11}=const.

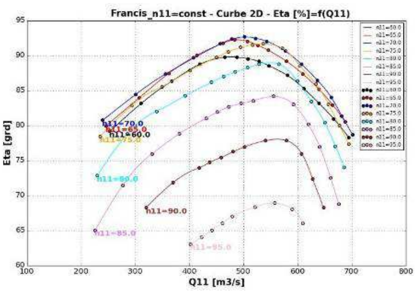


Figure 14. $\eta = f(Q_{11})$ 2D curves for n_{11}=const.

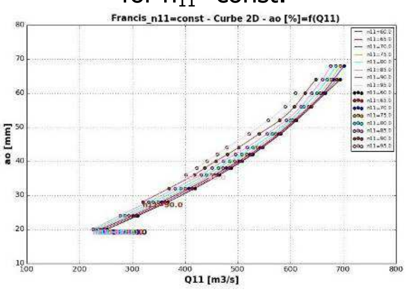


Figure 15. $a_o = f(Q_{11})$ 2D curves for n_{11}=const.

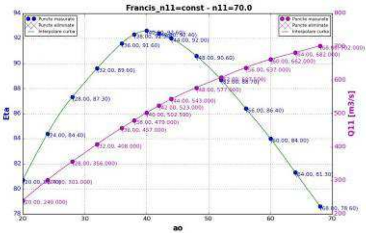


Figure 16. $\eta = f(a_o)$ and $Q_{11} = f(a_o)$ 2D curves for n_{11}=70

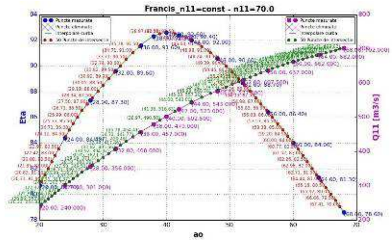


Figure 17. $\eta = f(a_o)$ and $Q_{11} = f(a_o)$ 2D curves with points $\eta = const.$

3.4. The "HILL CHART" button

The **Hill Chart** button allows the user to specify the desired efficiency values for calculating and plotting the hill chart. By pressing this button, a window will open that provides information about the maximum and minimum efficiency of the current database and allows the imposition of a minimum and maximum efficiency, as well as the pitch for which the hill chart will be calculated and drawn. Also in this window, in the **Valori particulare** field, particular values of the intersection efficiency can be specified and the color map for the hill chart display can be selected. Plotting of the hill chart is done in several steps. In the first stage, the measured parametric primary curves intersect with the imposed efficiency values. These points shall be submitted in the **Puncte de intersecție cu randament constant** table. In the second stage, $\eta = f(n_{11}, Q_{11})$ the surface intersects with constant efficiency values.

For a set of input data considered to be measured at a_o=const., Figure 18 shows the $\eta = f(n_{11}, Q_{11})$ 3D surface, Figure 19 shows the 3D intersection curves with the constant efficiency values and Figure 20 shows the hill chart.

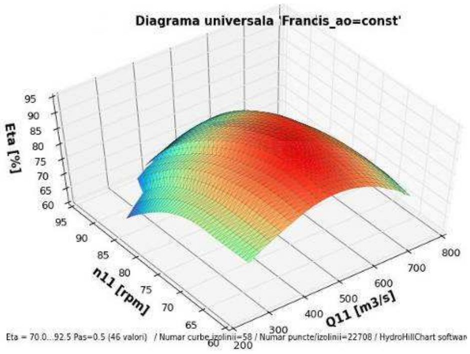


Figure 18. $\eta = f(n_{11}, Q_{11})$ 3D surface for a_o=const.

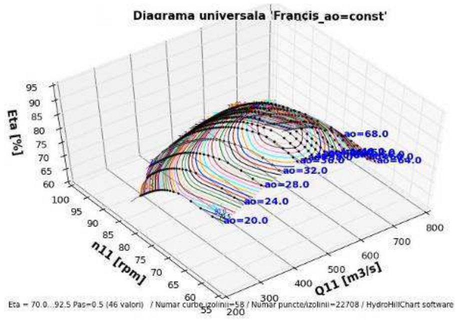


Figure 19. Intersection curves with constant efficiency values for a_o=const.

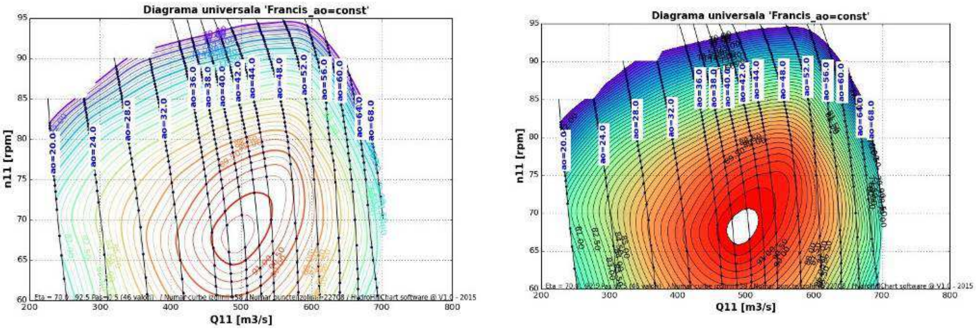


Figure 20. Universal characteristic for Francis runner at a_o=const.

For the same set of input data considered to be measured at n_{11}=const., Figure 21 shows the $\eta = f(n_{11}, Q_{11})$ 3D surface, Figure 22 shows the 3D intersection curves with the constant efficiency values and Figure 23 shows the hill chart.

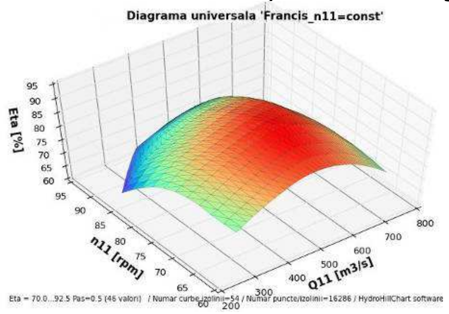


Figure 21. $\eta = f(n_{11}, Q_{11})$ 3D surface for n_{11}=const.

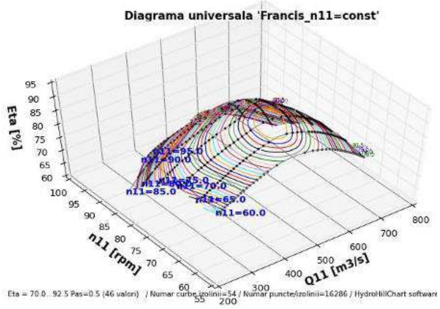


Figure 22.Intersection curves with constant efficiency values for n_{11}=const.

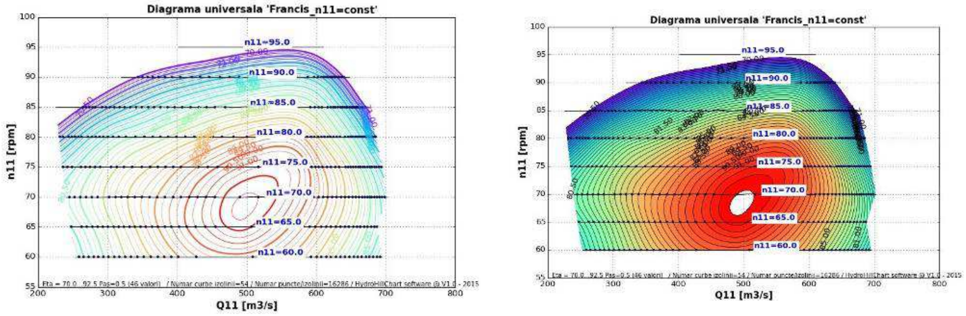


Figure 23. Universal characteristic for Francis runner at n_{11}=const.

3.5 The comparison of the hill charts

Figure 24 shows the set of discrete points (Q_{11}, n_{11}) with associated values (a_o,η), used as input data for the a_o=const. and n_{11}=const. measuring scenarios and for the calculation of the two hill charts, from Figures 20 and 23. Curves a_o=const. and associated points are plotted on Figure 24. For version n_{11}=const., the points used as input data are those located in the speed range of 60 ÷ 95 rpm, with a step of 5 rpm.

The comparison of these characteristics is shown in Figure 25, where the continuous lines represent the isolines of the hill chart, calculated for a_o=const measuring scenarios, and the dotted lines represent the isolines of the hill chart, calculated for n_{11}=const. measuring scenarios. As shown in the figure, the difference between the isolines is insignificant and that validates the interpolation algorithms used to calculate the hill chart with the **HydroHillChart** application.

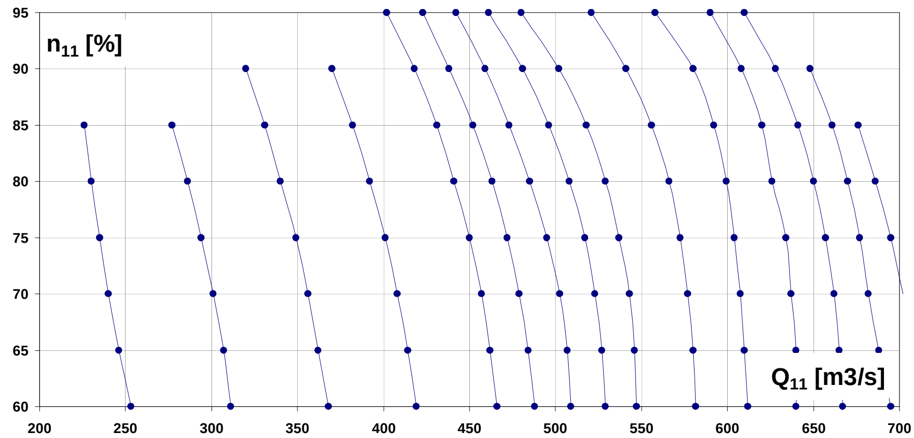


Figure 24. Discrete points used as input data

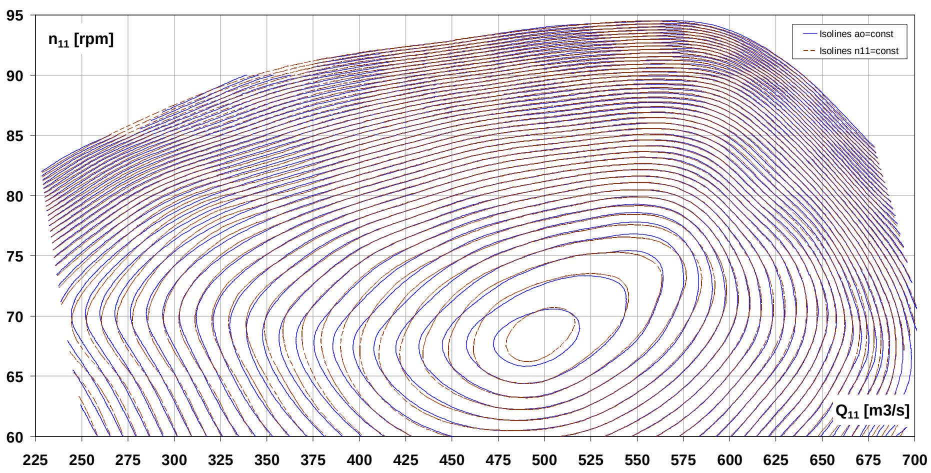


Figura 25. The hill charts comparison for a_o/n_{11}=const. scenarios

3.6 The "EXCEL" button

The **Excel** button exports data to an Excel file that contains the measured points and the numerical / graphical results of the processing operations which have been performed on the data. The Excel file will contain: a sheet called **Date măsu-**

rate in which information about the selected runner, the number of measured points, the number of points removed, and a table of measured data are stored, a sheet called **Intersecții** where the table with the calculated points of intersection with constant efficiency is saved and a sheet called **HillChart** where a table containing the coordinates of constant efficiency isolines is saved. All the data is expressed as graphs also.

4. Conclusions

The paper presents the **HydroHillChart - Francis module** application, a complex application that is used for the hill chart calculation of Francis hydraulic turbine models. The hill chart calculation can be done for two different sets of input data, depending on the constant parameter on which the measurements were made: a_o=const. or n_{11}=const. The application provides a rich set of tools for the graphical visualization of functional dependencies specific to a Francis turbine: the hill chart calculation, the curves / points of intersection with n_{11}/Q_{11}, the export of results in common programs: Excel, Word, PDF.

5. Acknowledgments

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[2] Nedelcu D., Bostan A., Peris-Bendu F., HydroHillChart – *Pelton Module. Software for Hill Chart Calculating of the Pelton Hydraulic Turbines*, Analele UEMR, Fascicula Inginerie, XXII, Nr.1, 2015.
[3] Bostan A., Nedelcu D., Peris-Bendu F., *The Hill Chart Calculations for Pelton Runner Models using the HydroHillChart - Pelton Module Software*, Analele UEMR, Fascicula Inginerie, XXII, Nr.1, 2015.

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