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

*The paper presents the **HydroHillChart** - Pelton module application, used to calculate the hill chart of the Pelton hydraulic turbine models, by processing the data measured on the stand. In addition, the tools offered by the application such as: interface, menu, input data, numerical and graphical results, etc. are described.*

Keywords: turbine, Pelton, runner, hill chart, Python

1. Introduction

The design of hydraulic turbines is based on energetic and cavitation characteristics, obtained by measuring the turbine models in specialized laboratories. For Pelton turbines, the energetic characteristic expresses the dependence from the following sizes: unitary speed n_{11r} , unitary flow Q_{11r} , efficiency η , injector needle opening S [1], [2]. The methods used for determining these features, based on experimental data acquired for different models of hydraulic turbines, are laborious and sometimes subjective. The creation of a specialized application has the purpose of objectifying the process used to determine these features. The software, called **HydroHillChart**, was created using the Python programming language and associated libraries [3]. This paper will present the Pelton module of the application, which, for interpolation, uses cubic spline function type.

2. The main menu of HydroHillChart

Figure 1 shows the main menu of **HydroHillChart**. **File** option provides the ability to choose the type of turbine for which the hill chart will be calculated (Pelton, Francis or Kaplan turbine).

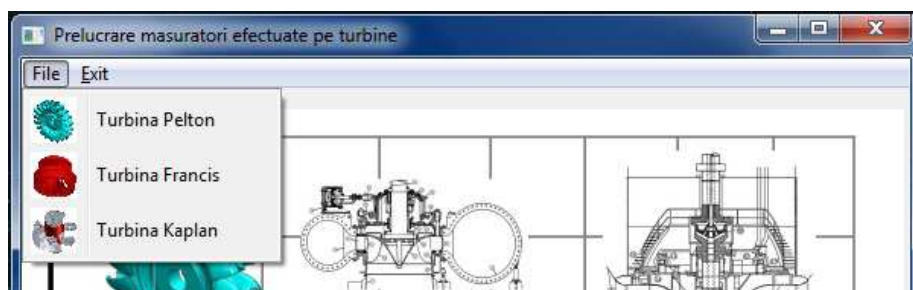


Figure 1. The main menu of **HydroHillChart** application

3. The Pelton module

Pelton turbine option, from main menu, displays a window with a specific interface for Pelton module, figure 2, composed of: toolbar, measured data table called **Puncte măsurate** (in which measured data for a model runner are loaded) and the table called **Puncte de intersecție cu randament constant** (where the application stores values resulting from the intersection of primary curves with constant efficiency).

56 Puncte masurate						275 Intersectii cu randamente constante				
ID punct	S [mm]	Q11 [m ³ /s]	n11 [rot/min]	Eta [%]	Punct eliminat	Q11 [m ³ /s]	n11 [rot/min]	Eta [%]	S [mm]	
50	5.0000	43.000000	27.500000	76.000000	<input type="checkbox"/>	1	43.0000	27.5000	76.0000	5.0000
43	5.0000	43.000000	30.000000	78.300000	<input type="checkbox"/>	2	43.0000	28.0412	76.5000	5.0000
36	5.0000	43.000000	32.500000	80.500000	<input type="checkbox"/>	3	43.0000	28.5840	77.0000	5.0000
29	5.0000	43.000000	35.000000	82.000000	<input type="checkbox"/>	4	43.0000	29.1281	77.5000	5.0000
22	5.0000	43.000000	37.500000	82.800000	<input type="checkbox"/>	5	43.0000	30.2179	78.5000	5.0000
15	5.0000	43.000000	40.000000	82.900000	<input type="checkbox"/>	6	43.0000	30.7630	79.0000	5.0000
8	5.0000	43.000000	42.500000	81.200000	<input type="checkbox"/>	7	43.0000	31.3134	79.5000	5.0000
1	5.0000	43.000000	45.000000	78.000000	<input type="checkbox"/>	8	43.0000	31.8824	80.0000	5.0000
51	10.0000	83.750000	27.500000	78.700000	<input type="checkbox"/>	9	43.0000	32.5000	80.5000	5.0000
44	10.0000	83.750000	30.000000	82.000000	<input type="checkbox"/>	10	43.0000	33.2037	81.0000	5.0000













Figure 2. Interface of **Pelton** module

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;
- **S [mm]** - represents the injector needle opening of a Pelton runner;
- **Q₁₁ [m³/s]** - represents the unitary flow;
- **n₁₁ [rot/min]** - represents the unitary speed;
- **η [%]** - represents the efficiency;
- **Punct eliminat** - allows removal of a measured point, by selecting a **Check Box**.





3.1. The Pelton module toolbar

The Pelton module toolbar is located at the top of the window and includes control buttons marked with specific icons, figure 2, which fulfill the following functions:

-  - informative icon for Pelton runner, without a related function;
-  **New** - create a new database for Pelton runners;
-  **Open** - opening and loading an existing database for Pelton runners;
-  **Info** - provides information about the current database;
-  **Data** - input data visualization in graphic form: 3D curves and $\eta = f(n_{11}, Q_{11}, S)$ 3D surface, respectively $\eta = f(n_{11})$ 2D curves at S parameter and $S = f(Q_{11})$;
-  **Hill Chart** - calculating and plotting universal characteristic for a number of specified efficiencies values;
-  **n₁₁** - imposing a double unitary speeds n_{11} to calculate the characteristics' intersection $\eta = f(n_{11}, Q_{11})$ for determining the curve $\eta = f(Q_{11})$ respectively $\eta = f(S)$;
-  **Q₁₁-n₁₁** - imposing a double unitary speeds n_{11} and unitary flow Q_{11} , followed by hill chart 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 **HydroHillChart** software.

3.2. The Graphics Toolbar

For each graph generated by the **HydroHillChart** software, a toolbar with command buttons marked with specific icons appears at the bottom of the window and it performs 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 "NEW" button

The **New** button allows the creation of a new database with the same structure as the **Puncte măsurate** table, Figure 2. To create a new database the following types of information must be completed, Figure 3: turbine type name, database filename, the period when the measurements took place, the person responsible for the performed measurements, additional information; the Excel button allows the selection of the file from which the measurements are taken. After filling in the required data, by pressing **Creare** button, a database will be created with the name found in the **Denumire fisier** box. Measured point values, taken from Excel, will be loaded in the **Puncte măsurate** table, and the application sends a message with the specified path where the new database was saved.

3.4. The "OPEN" button

The **Open** button function is to open and load, into the software, an existing database. Following this operation, the **Puncte măsurate** table will be emptied and then rewritten with values from the selected database.

3.5. The "INFO" button

The **Info** button provides information about the current database, Figure 4: turbine and database name, the period when the measurements took place, the person responsible for the performed measurements, the file in which the measured data were taken, the number of measured and eliminated points, the minimum and maximum unitary speed, unitary flow, injection needle opening and efficiency.

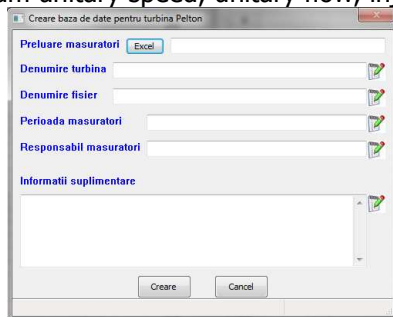


Figure 3. The window for creating a new database

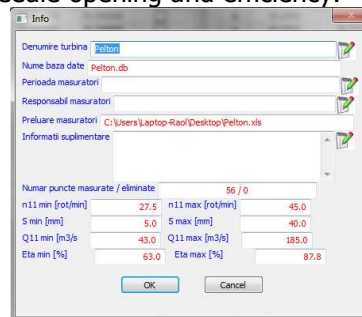


Figure 4. Information about the current database

3.6. The "DATA" button

The **DATA** button shows the input data from a graphical viewpoint:

- $\eta = f(n_{11}, Q_{11}, S)$ 3D surface, Figure 5;
- $\eta = f(n_{11}, Q_{11})$ 3D curves for S parameter, Figure 6;
- $\eta = f(n_{11})$ 2D curves for S parameter, Figure 7;
- $S=f(Q_{11})$ 2D curve, Figure 8.

3.7. The "HILL CHART" button

The **Hill Chart** button allows the user to specify the desired efficiency 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 the minimum and maximum efficiency, as well as the step for which the hill chart will be calculated and drawn, Figure 9. Also, in the **Valori particolare** field, particular values of the intersection efficiency can be specified and the color map for the hill chart display can be selected. The **OK** button starts the procedure of calculation and plotting of the hill chart for the current Pelton turbine model. The plotting of the universal characteristic is made in several steps. In the first stage, the primary curves $\eta = f(n_{11})$ measured for different positions of the injector needle S are intersected with the 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, Figure 10, leading to the isolines from Figure 12. Figure 11 shows the 3D intersection curves with constant efficiency values.

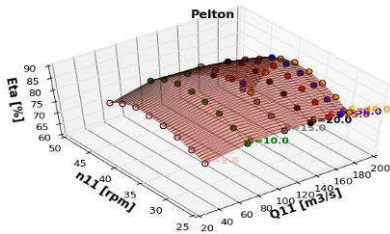


Figure 5. $\eta = f(n_{11}, Q_{11}, S)$ 3D surface

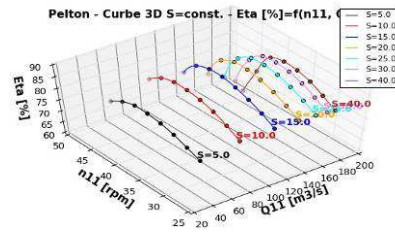


Figure 6. $\eta = f(n_{11}, Q_{11})$ 3D curves

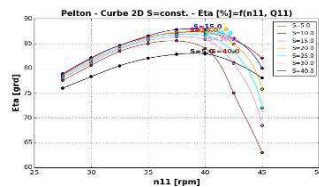


Figure 7. $\eta = f(n_{11})$ 2D curves for S parameter

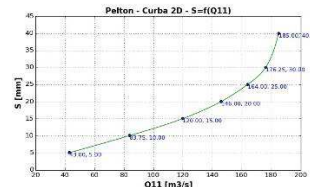


Figure 8. $\eta = f(n_{11})$ 2D curves for S=const.

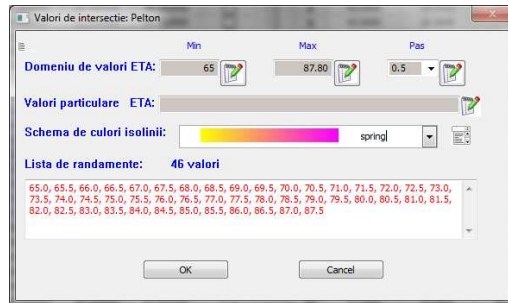


Figure 9. The window for specifying the values of efficiency

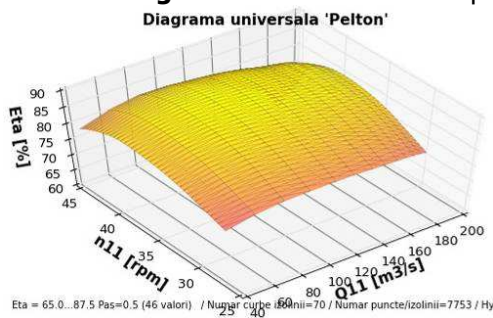


Figure 10. $\eta = f(n_{11}, Q_{11})$ 3D surface

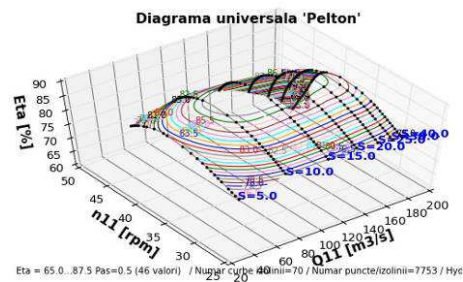


Figure 11. Intersection curves with constant efficiency values

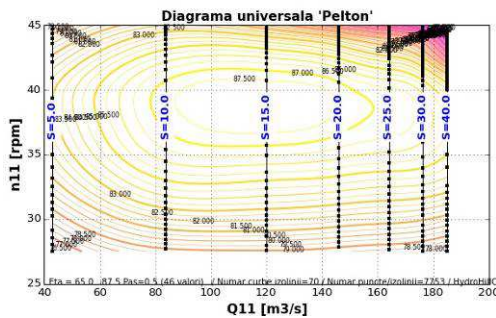
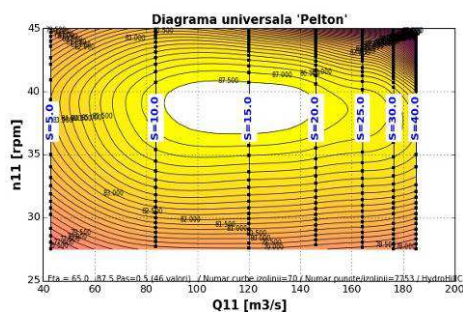


Figure 12. The hill chart for Pelton runner



3.8. The "n₁₁" button

The **n₁₁** button allows the imposition of a constant unitary speed in order to calculate the intersection curve of the universal characteristic. The efficiency value is inserted through the window from Figure 13, followed by the calculation/plotting $\eta = f(n_{11}, Q_{11})$ of the 3D curves and intersection curve, Figure 14, respectively of the 2D curves $\eta = f(Q_{11})$ and $\eta = f(S)$, Figure 15 and Figure 16, for a unitary speed **n₁₁**, which is required. Numerical and graphical results are stored in an Excel file into the application folder.

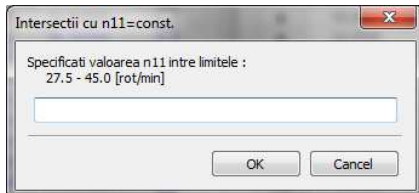


Figure 13. Window input value n_{11}

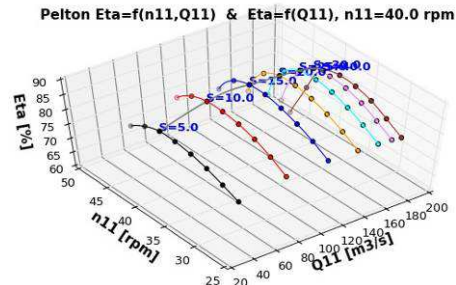


Figure 14. $\eta = f(n_{11}, Q_{11})$ 3D curves for n_{11} required

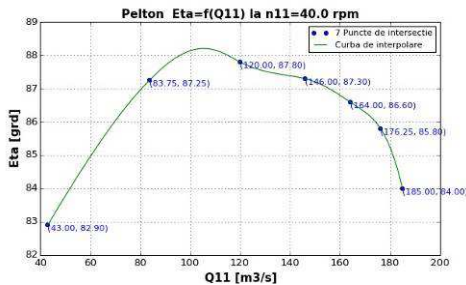


Figure 15. $\eta = f(Q_{11})$ 2D curve for n_{11} required

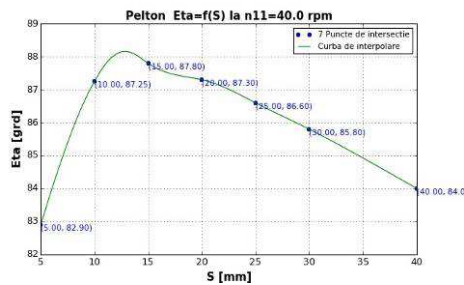


Figure 16. $\eta = f(S)$ 2D curve for n_{11} required

3.9. The " $n_{11} - Q_{11}$ " button

The $Q_{11} - n_{11}$ button allows the imposition of a unitary speed n_{11} and a unitary flow Q_{11} , in order to calculate the efficiency value. Q_{11}/n_{11} values are imposed through the window from Figure 17, followed by the calculation/plotting $\eta = f(n_{11}, Q_{11})$ of 3D curves, of a curve and a point of intersection, Figure 18, respectively of 2D curves $\eta = f(Q_{11})$ and $\eta = f(S)$, Figure 19 and Figure 20, which contains the point of intersection. Numerical and graphical results are stored in an Excel file into the application folder.

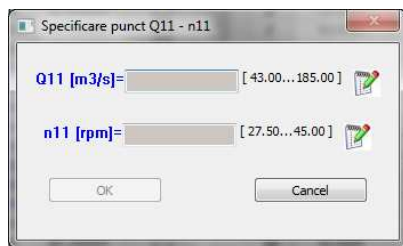


Figure 17. Window input values Q_{11} and n_{11}

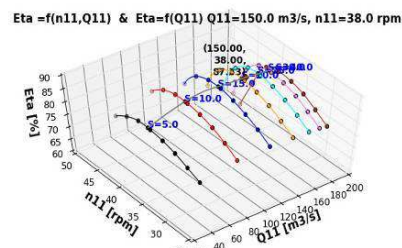


Figure 18. $\eta = f(n_{11}, Q_{11})$ 3D curves for Q_{11}/n_{11} required

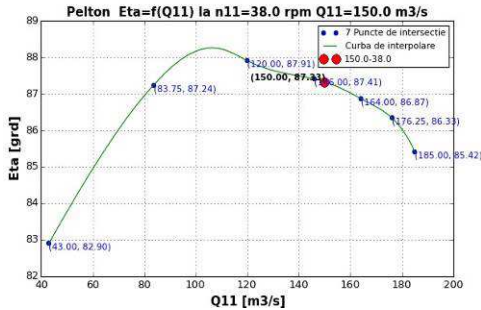


Figure 19. $\eta = f(Q_{11})$ 2D curve for Q_{11}/n_{11} required and the intersection point

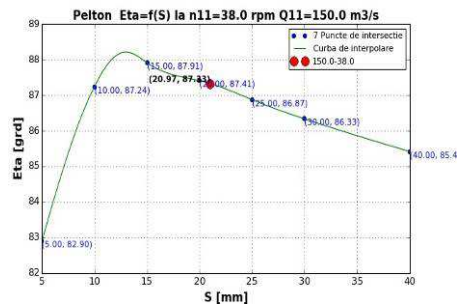


Figure 20. $\eta = f(S)$ 2D curve for Q_{11}/n_{11} required and the intersection point

3.10. 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 măsurate**, Figure 21, in which information about the selected rotor, the number of measured points, the number of points removed, and a table of measured data are stored, a sheet called **Intersecții**, Figure 22, in which the table with the calculated points of intersection with constant efficiency is stored and a sheet called **HillChart**, Figure 23, in which a table containing the coordinates of constant efficiency isolines is stored. The data is expressed through graphs as well.

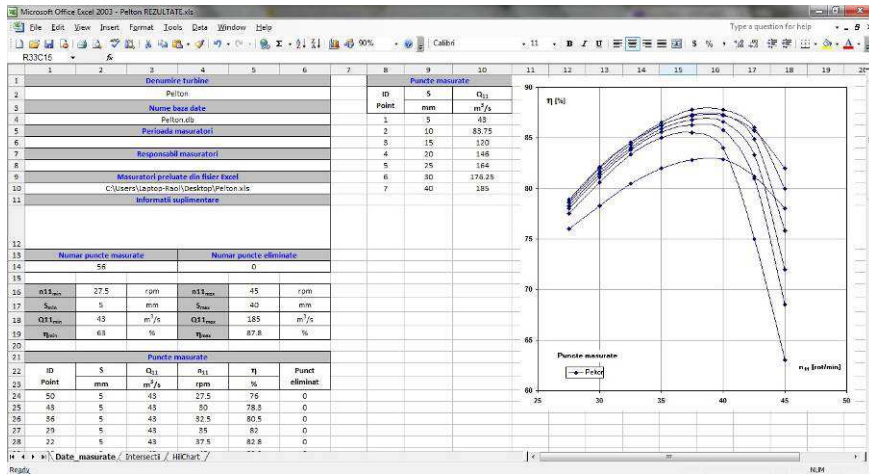


Figure 21. The **Date măsurate** sheet from Excel file

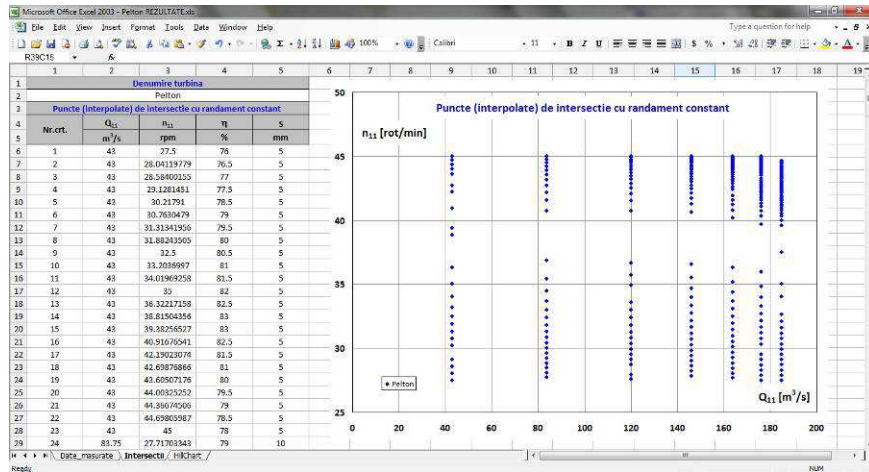


Figure 22. The **Intersectii** sheet from Excel file

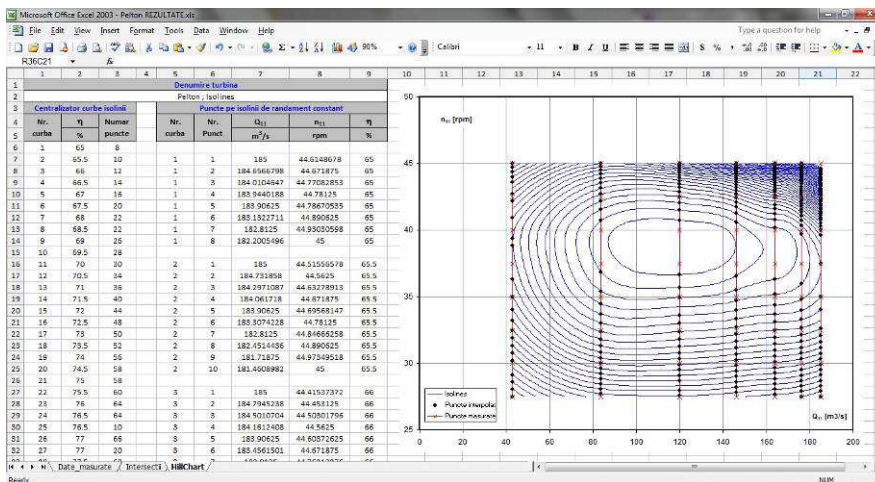


Figure 23. The **HillChart** sheet from Excel file

4. Conclusions

The paper presents the **HydroHillChart - Pelton module** application, a complex application that allows the calculation of the hill chart for Pelton hydraulic turbine models. The application was created using the Python programming language, while the used interpolation functions are cubic spline function type.

Based on the measured data of the model, the application generates the hill chart for Pelton turbine models, providing the necessary tools in the design of Pelton turbines: graphic visualization of functional dependencies, intersections in the hill

chart, generation of numerical results and their export in usual programs: Excel, Word, PDF.

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