
Pump fitting Documentation

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CHAPTER 1

Introduction

The Pump Fitting Tool is used generate the input to a pump model for use in the decision support system RTC-Tools 2. It reads user-supplied pump performance data and calculates the coefficients of polynomials that approximate the characteristics for pump power, the boundaries of the working area, and the relations to compute the shaft speed of the pump. The script can be used for rotordynamic pumps (both constant and variable speed) and screw pumps.

CHAPTER 2

Input for the script and preprocessing

All the input data for the script is stored in a csv file like shown below. The following fields should be filled:

1. Pump type: 0 for variable speed pumps, 1 for constant speed pumps, and 2 for screw pumps
2. Reference pump speed N_{ref} (rpm)
3. The Q-H relation of the pump for shaft speed N_{ref} : flow rate Q (m^3/s) and head H (m)
4. Either power (W) or efficiency (-) for the given flow rates

These are the necessary inputs for a simple pump, the other features can be left as default.

G22 fx												
	A	B	C	D	E	F	G	H	I	J	K	L
1	Q	Head	Eff	Power			Data					
2	0	13	0				Dref	1				
3	0.490515	9.869565	0.7				Nref	585				
4	0.549051	9.26087	0.75				Loss h	1				
5	0.618428	8.434783	0.77				Loss q	1				
6	0.702981	7.304348	0.8				Ackeret	0				
7	0.750678	6.652174	0.77				Min eff	0.5				
8	0.826558	5.478261	0.75				Min rpm	0.4				
9	0.872087	4.73913	0.7				Extra curv	0				
10	0.913279	4.086957	0.65				Constant s	0				
11	0.947967	3.521739	0.6				Actual rpm	1				
12							Point	0.702981	7.15			
13							Line 1	0	-1	0	0	1
14							Line 2	0	0	0	-1	5
15							Line 3	0	0	0	4	5
16								Q2	Q	H2	H	number
17												
18												

There are several extra options in the excel file:

- The loss coefficients, $Loss_h$ and $Loss_q$, are used to specify system head loss $Loss_h$ at a specific flow rate $Loss_q$.
- *Ackeret*: if the value is 1, then Ackeret correction is used. It can be 0 or 1.
- *Min_eff*: The minimum efficiency used to bound the working area. It can vary from 0 to 1.
- *Min_rpm*: The minimum pump speed fraction used to bound the working area. It can vary from 0 to 1.
- *Actual_rpm*: Only used if the given N_{ref} is not the maximum speed. It is the ratio between N_{ref} and the maximum speed. If N_{ref} is the maximum pump speed it can be left empty or filled with 1. (Meaning that N_{ref} is the 100% of the maximum speed.)
- *Loss_coef*: the system losses can be given with a loss coefficient. The head losses are calculated by multiplying this coefficient with the square of the flow rate.
- *Extra_curves*: Extra curves can be given to further restrict the working area. The curves can be given below, and the number of the curves should be defined here. If you use this option, then you also have to fill in the field *Point*. Otherwise fill in 0. Further explanation about these items can be found in section [Working area selection](#).

Note:

- The Q values should be in increasing order
 - Power should reflect energy consumption, i.e. grid power (in case of an electric drive) or motor power (in case of a diesel engine drive)
 - If efficiency η is supplied, the power P will be calculated by $P = 9800QH/\eta$
 - Pump head H can be either static or manometric head
 - If manometric head H_{man} is given, the system head losses should be specified using either ($Loss_q$, “ $Loss_h$ ”) or $Loss_coef$
 - If static head H_{stat} is given, either the power should be supplied or the static efficiency H_{stat} based on static head i.e. $H_{stat} = 9800QH_{stat}/P$ should be provided
 - If the static head is given, both $Loss_h$ and $Loss_coef$ should be equal to zero.
-

CHAPTER 3

To run the script

You can set the name of your input file in the file `main.py`.

```
43 csv_file_name = 'Kuijkm_input_extrap'
44 csv_file_name = 'Pannerling_input_extrap'
45 #csv_file_name = 'Pannerling_input'
46 #csv_file_name = 'Kuijkm_input'
47 #csv_file_name = 'ExampleHomePage'
48 #csv_file_name = 'Beuningen1_input_extrap' #This is a constant speed pump
49 #csv_file_name = 'bumal'
50
51
52 linear = 0
53
54 #This function reads the variables from the csv
55 P, E, Q, Hread, dref, N, losshref, lossqref, minimum_efficiency, minimum_rpm,
↪ point_coordinates, ackeret_correction, extra_line_coef, pump_type, loss_coefficient,
↪ maximum_rpm, maximum_calc_rpm, constant_head = _csv_reader(csv_file_name)
56
57 #This function removes the losses if they are expressed in Q and H
```

How to find the input data?

There are four kinds of data needed to run the script. All can be read from the pump curves.

4.1 1. Pump type

The type of pump should be specified. This information is given in the documentation of the pump.

4.2 2. Q-H relations

The Q-H relations can be read from a pump curve. A pump system curve contains the flow rate-head relations for a certain shaft speed. There might be more curves for different speeds. For this program, we need the curve belonging to the maximum speed. The head might be the static head or manometric head. Or it is also possible that both curves are given. In case the power is given later, it does not have much effect which curve is read. It is recommended to read the static head curve, as it is already corrected for the system losses. If only the manometric head curve is given, the losses can be approximated as described in the following section. In case the power is not given, then the efficiency curve should be read. Make sure that values for head and efficiency are consistent i.e. power P should follow from $P = 9800 \cdot Q \cdot H / \eta$.

4.3 3. Pump speed

This is the speed corresponding to the system curve read in point 2. Often the data is located on the drawing itself. Give the value in rpm.

4.4 4. Power or efficiency

Either the power or the efficiency should be given. If both are available, it is recommended to give the power. The advantage is that then the static head can be used and the static efficiency can directly be obtained.

Approximation of the losses

The manometric head (H_{man}) of a pump is a measure of the pressure difference across the pump, from inlet to outlet flange. Part of this pressure is required to overcome the frictional losses in the piping system, and the remainder is used to maintain the water level difference across the pumping station – the so-called static head (H_{stat}). Thus, the static head is always lower than the manometric head and is calculated by

$$H_{stat} = H_{man} - H_{losses}$$

Head losses for a given system depend on flow rate. It is assumed here that head losses vary with flow rate squared.

There are three possible ways to account for the losses:

- 1) by specifying a loss coefficient C

$$H_{stat} = H_{man} - CQ^2$$

- 2) by specifying a known head loss (H_{loss}) for certain flow rate (Q_{loss}). For any flow rate Q, the relation between static and manometric head reads

$$H_{stat} = H_{man} - H_{loss}(Q/Q_{loss})^2$$

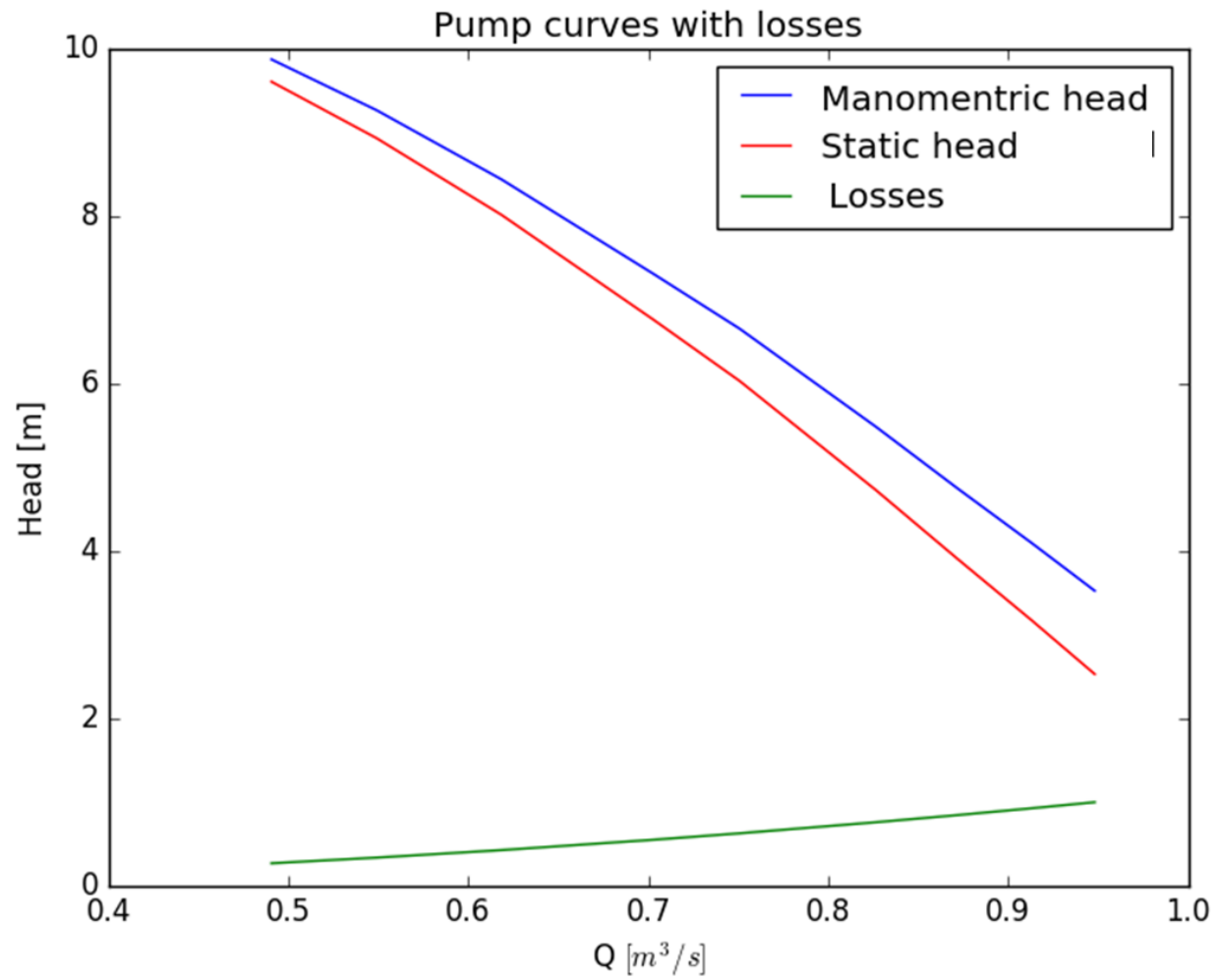
where $H_{manometric}$ is the resulting head that the pump has to overcome.

If head loss correction is used, the program is already reading the compensated heads.

- 3) by reading directly the static head curve.

In the figure below a case with loss coefficient C=10 is plotted. It can be seen that the losses increase quadratically with flow rate.

Note: See if your data is given as static head or as manometric head.



Ackeret correction

The (manometric) efficiency of the pump is provided for a single shaft speed, either directly or through the power curve. For a variable speed pump, the efficiency would decrease with decreasing shaft speed due to a changing Reynolds number. The Ackeret correction is used to take this into account:

$$E = 1 - (1 - E_{ref})(N_{ref}/N)^\alpha$$

where (E_{ref}) is the original and (E) is the corrected efficiency. α is the Ackeret parameter and its value is taken to be 0.15. N_{ref} and N are the original and the new pump speed respectively. The efficiency is bounded by 0 and 1. After this correction the power is also re-calculated. The reason is that the script (and the optimization) is working with the minimization of the power instead of efficiency.

Working area selection

The working area is bounded by the minimum and maximum shaft speed curves, and the minimum efficiency curves. These four curves are always present in case of variable speed and constant speed pumps. The exception is the screw pump. Additionally, the user can define additional curves (e.g. NPSH) that further restrict the working area. In case of additional curves, the user should also provide the coordinates of a point that is inside the working area.

7.1 Constant speed pumps

The basic four curves are used to select the working area. However, as there is only one shaft speed, there will be one curve instead of an area. This curve will be approximated with a straight line. In the input file the pump type should be set to constant speed pumps.

7.2 Screw pumps

It is possible to use to model screw pumps with this software package. In the input file the pump type should be set to screw pumps.

How does pump-fitting tools work?

The pump power is approximated with a second order convex function.

The efficiency is calculated as:

$$\eta = \frac{Q\rho gH}{P}$$

After calculation the losses and applying the Ackeret correction, the power surface is obtained by using the affinity laws:

$$\frac{H_b}{H_a} = \left(\frac{n_b}{n_a}\right)^2$$

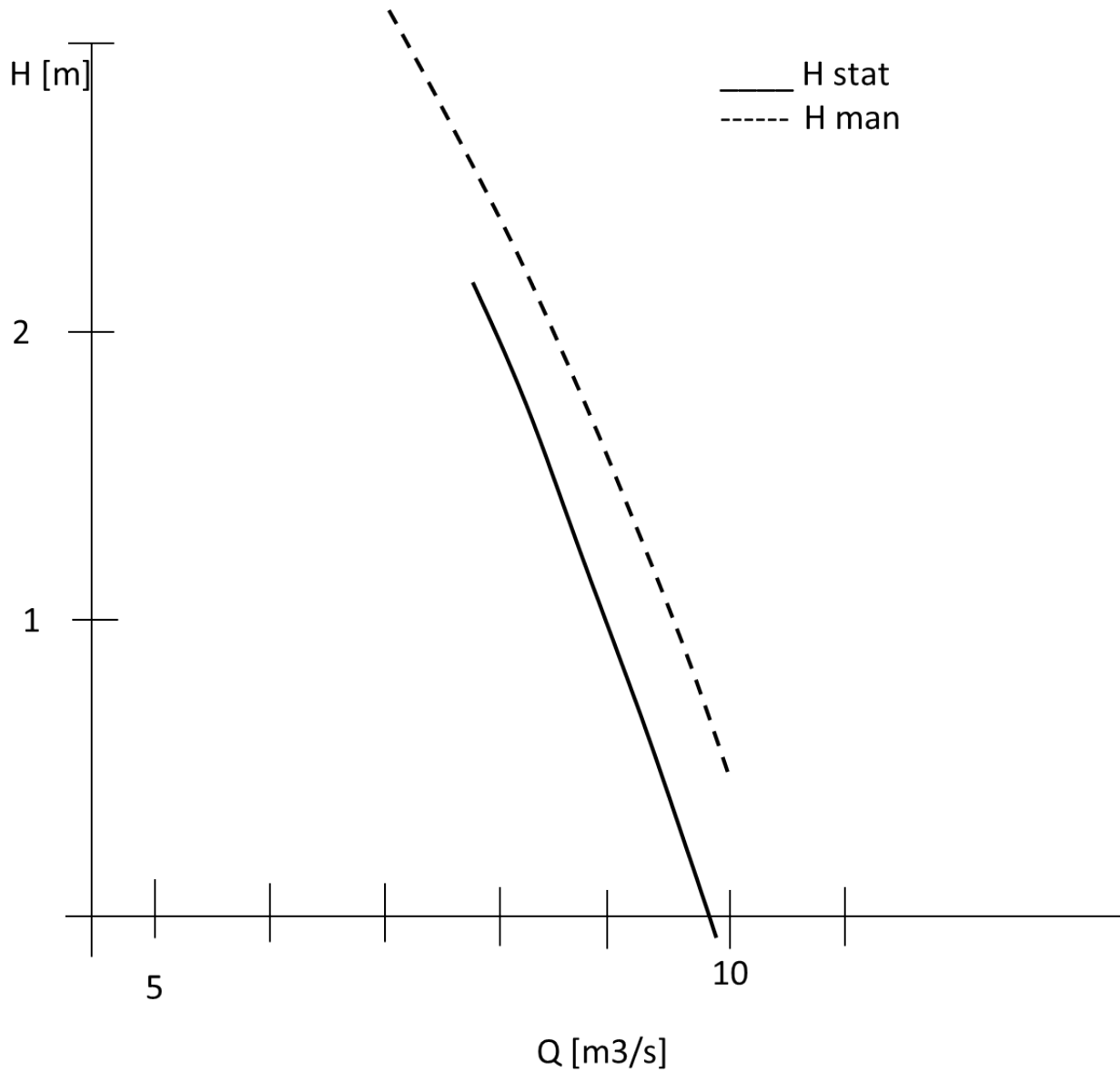
$$\frac{Q_b}{Q_a} = \frac{n_b}{n_a}$$

$$\frac{H_b}{H_a} = \left(\frac{P_b}{P_a}\right)^3$$

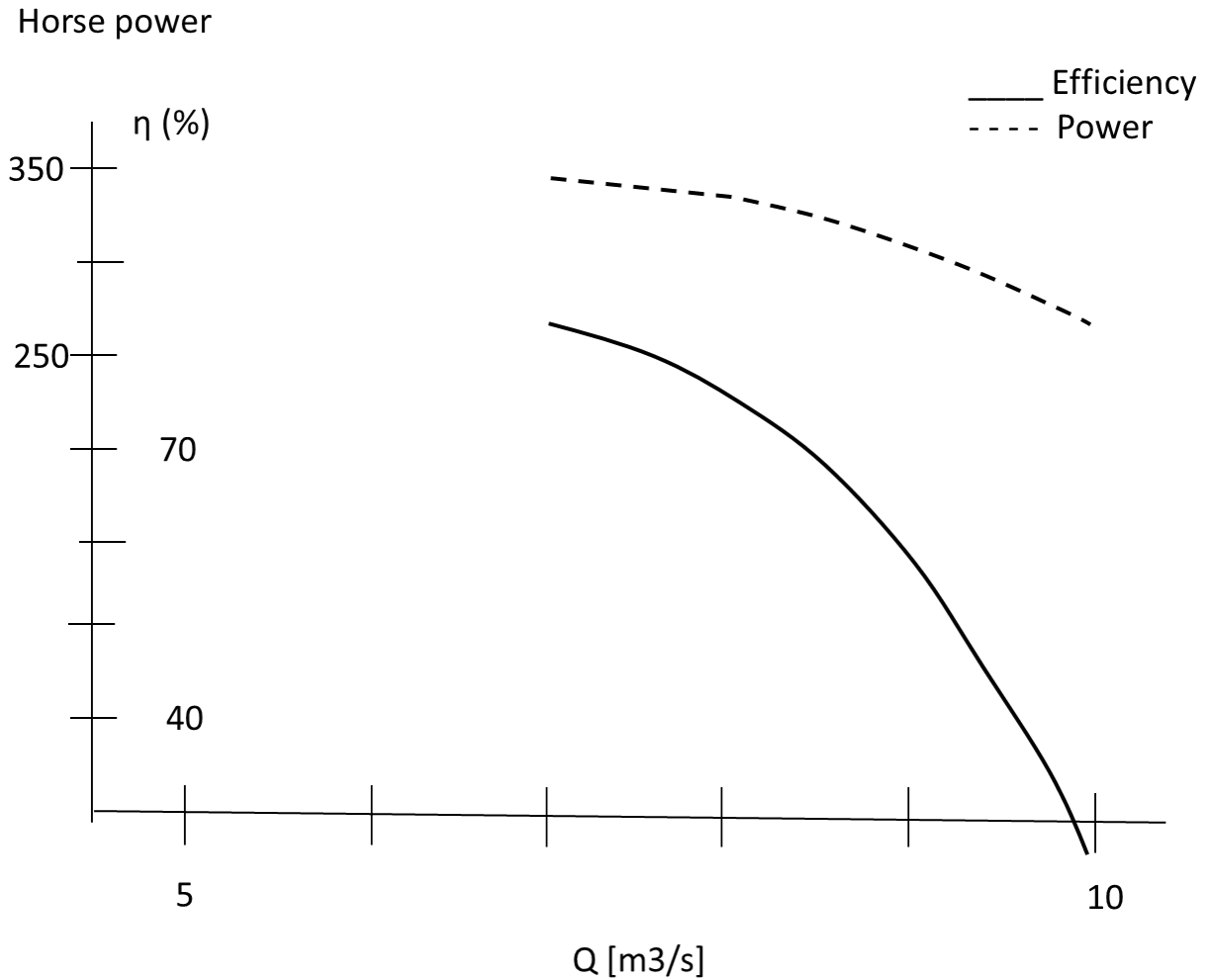
Step by step example

9.1 1. The available data

Suppose there is a variable speed pump. The following pump curves are given corresponding to 120.2 rpm. The first figure show the head curves



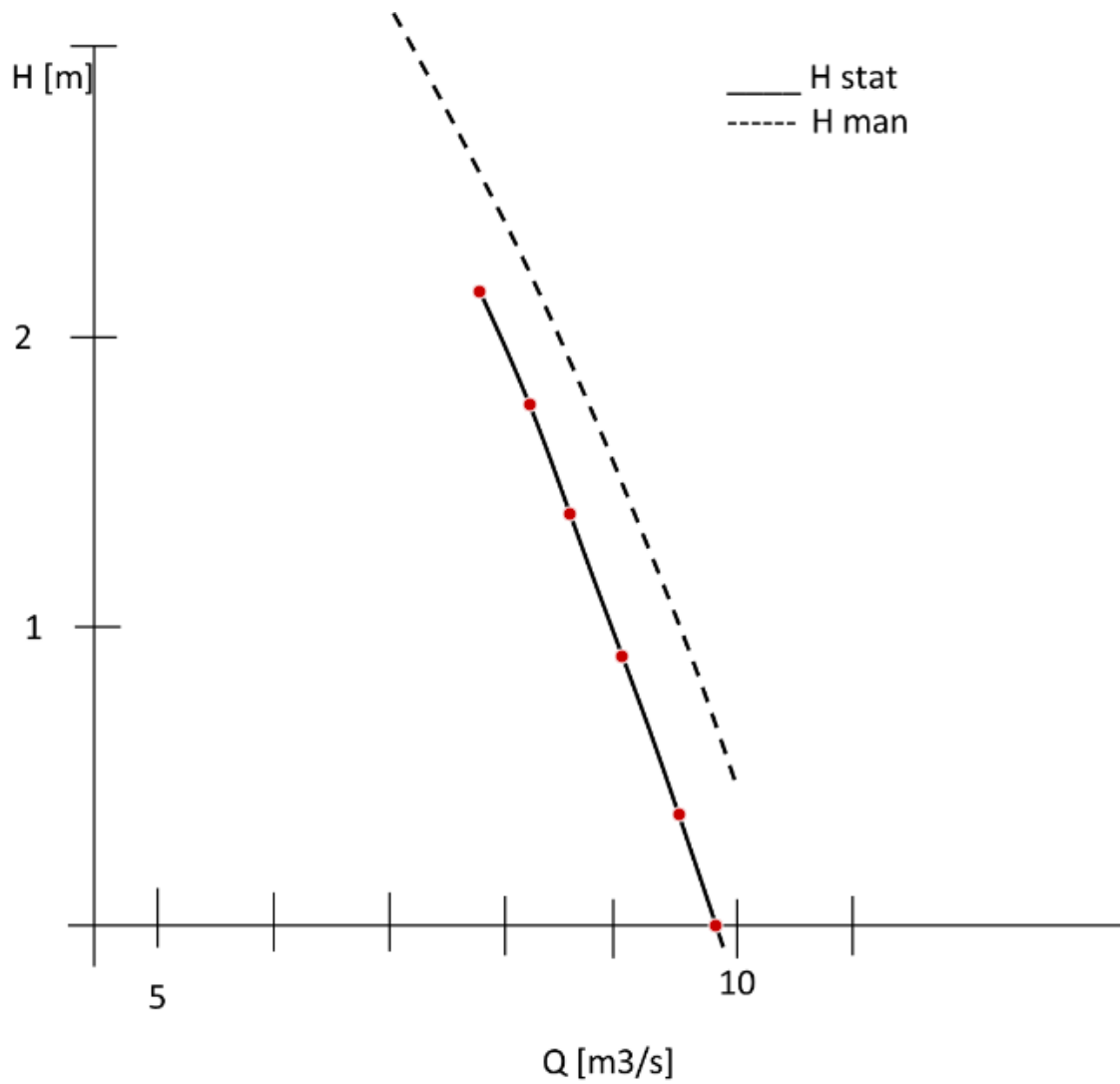
and the second one shows the power and the efficiency.



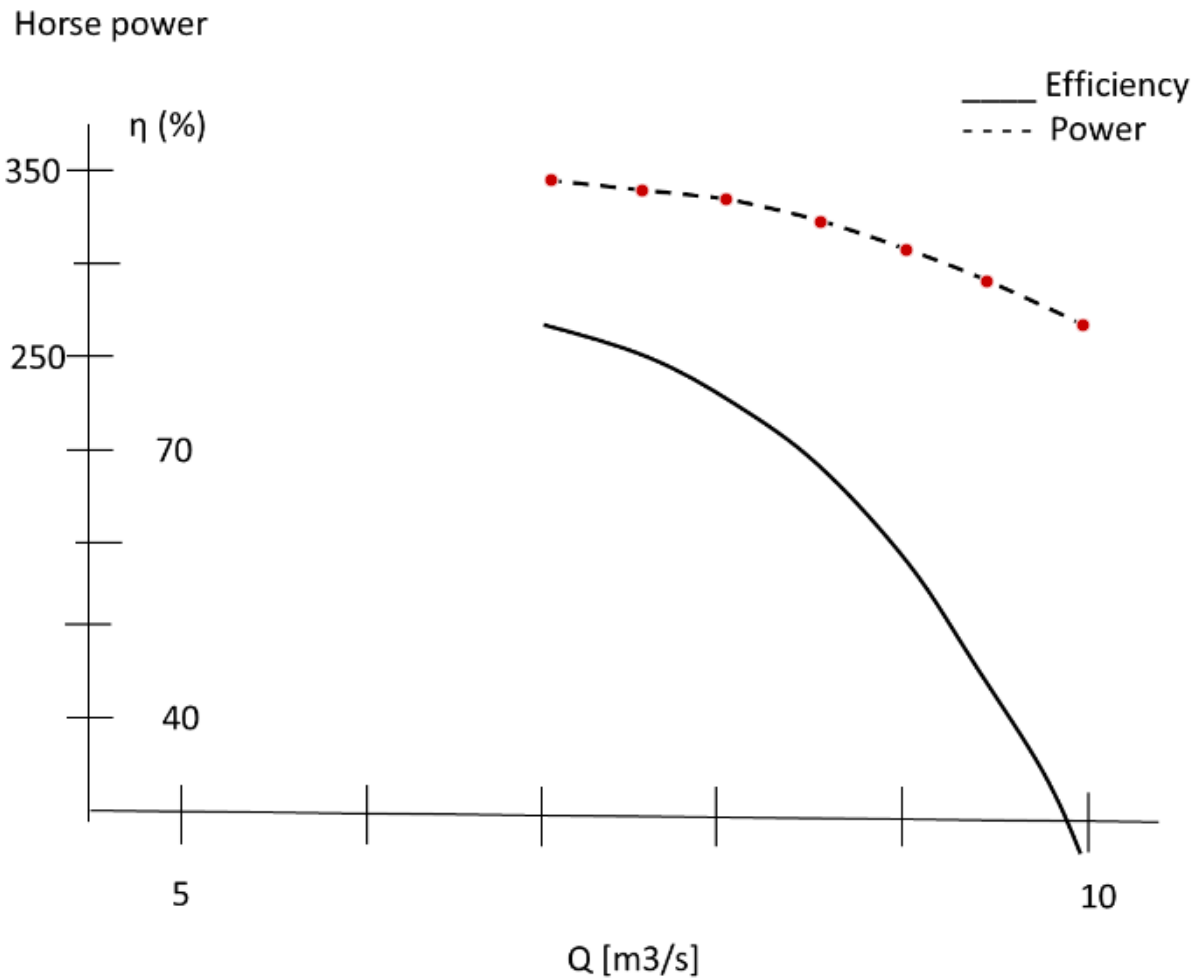
This data is enough to prepare the pump for the optimization.

9.2 2. Reading the data

First of all, the data should be read from the pump curves. Since the power curve is available, it is more convenient to read the static head than the manometric head; the static head curve is already corrected for the losses in the system and it is no longer required to determine the head loss $L_{\text{loss h}}$ or the head loss coefficient $L_{\text{loss coef}}$.



We read the power from the second graph.



After reading the data it can be organized to the following tables.

Q (m ³ /s)	H(m)
7.8	2.2
8.3	1.8
8.6	1.4
9.0	0.9
9.5	0.4
9.8	0.0

Note that the power was given in horse power and it should be converted to Watts.

Q (m ³ /s)	P(BHP)	P(W)
7.0	346.8	255051
7.5	341.6	251273
8.0	337.4	248154
8.5	325.7	239577
9.0	311.2	228904
9.4	294.8	216836
10.0	271.9	200016

9.3 2. Pre-processing the data

In order to create an input file for the pump fitting tools, every data point should have a Q, H and P value. So the data should be combined to one table by interpolation. In this case the Q values from the first table are kept (as they span a smaller horizon) and the power values are interpolated. Otherwise extrapolation would have been needed which is not recommended.

Q (m ³ /s)	H(m)	P(W)
7.8	2.2	249400
8.3	1.8	243010
8.6	1.4	237440
9.0	0.9	228900
9.5	0.4	214030
9.8	0.0	205620

9.4 3. Creating the input csv file

The table above should be copied to the csv file. The file should have the give format: 4 columns: discharge, head, efficiency, and power. The headings do not matter but the order of the variables does. The pump speed should be filled in a cell named `Nref`. There are two more data highlighted in the figure below: the minimum efficiency and the minimum shaft speed for defining the working area of the pump. In other words, what is the minimum efficiency under which the pump should not work. The number should be between 0 and 1. A default value can be 0.4 or 0.5. Same for the minimum shaft speed. Is there a minimum speed under which the pump should not work? Fill in as the fraction of the maximum speed (0-1). 0.4 can be a default value.

No other information is required. Note that the filed `Pump type` should be zero, as it is a variable speed pump. The csv file should look like this:

	A	B	C	D	E	F	G	H	I	J	K	L
1	Q	Hman	Eff	Power			Data					
2	7.8	2.2		249400			Dref	0				
3	8.3	1.8		243010			Nref	120.2				
4	8.6	1.4		237440			Loss h	0				
5	9	0.9		228900			Loss q	0				
6	9.5	0.4		214030			Ackeret	0				
7	9.8	0		205620			Min eff	0.4				
8							Min rpm	0.4				
9							Extra curv	0				
10							Pump type	0				
11							Point	0	0			
12							Loss coef	0				
13							Line 1	0	0	0	0	1
14							Line 2	0	0	0	0	0
15							Line 3	0	0	0	0	0
16								Q2	Q	H2	H	number

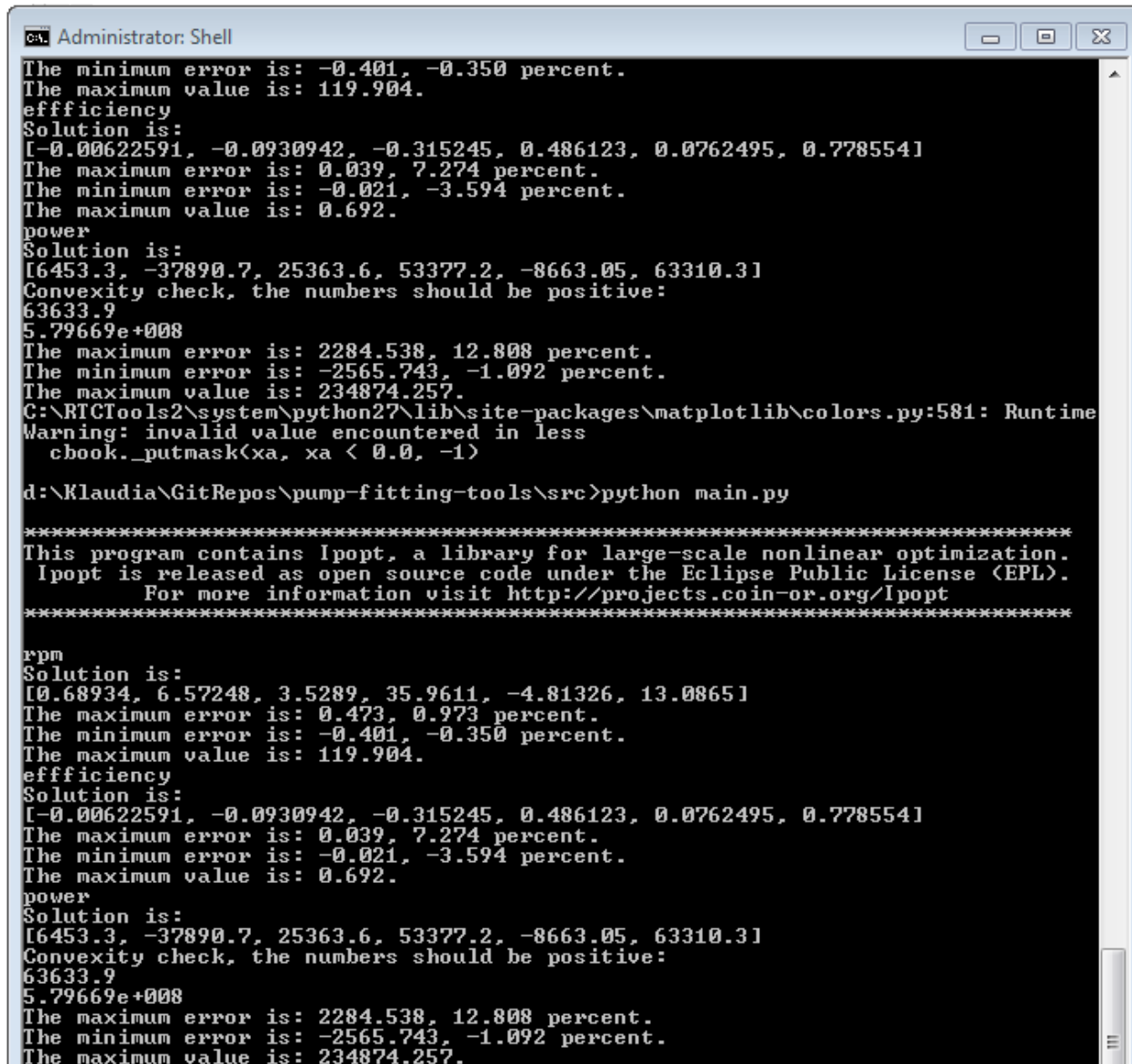
9.5 4. Running the program

First, the program should know that the data is located in a file `Example.csv`. It can be done by editing the file `main.py`. In the beginning of the file there is a line saying `csv_file_name = .` After the equality sign the file name

without extension should be typed.

Now the file can actually run by going to the folder `src` and typing `python main.py`.

After running the screen should look like:



```
Administrator: Shell

The minimum error is: -0.401, -0.350 percent.
The maximum value is: 119.904.
efficiency
Solution is:
[-0.00622591, -0.0930942, -0.315245, 0.486123, 0.0762495, 0.778554]
The maximum error is: 0.039, 7.274 percent.
The minimum error is: -0.021, -3.594 percent.
The maximum value is: 0.692.
power
Solution is:
[6453.3, -37890.7, 25363.6, 53377.2, -8663.05, 63310.3]
Convexity check, the numbers should be positive:
63633.9
5.79669e+008
The maximum error is: 2284.538, 12.808 percent.
The minimum error is: -2565.743, -1.092 percent.
The maximum value is: 234874.257.
C:\RTCTools2\system\python27\lib\site-packages\matplotlib\colors.py:581: Runtime
Warning: invalid value encountered in less
  cbook._putmask(xa, xa < 0.0, -1)

d:\Klaudia\GitRepos\pump-fitting-tools\src>python main.py

*****
This program contains Ipopt, a library for large-scale nonlinear optimization.
Ipopt is released as open source code under the Eclipse Public License (EPL).
For more information visit http://projects.coin-or.org/Ipopt
*****

rpm
Solution is:
[0.68934, 6.57248, 3.5289, 35.9611, -4.81326, 13.0865]
The maximum error is: 0.473, 0.973 percent.
The minimum error is: -0.401, -0.350 percent.
The maximum value is: 119.904.
efficiency
Solution is:
[-0.00622591, -0.0930942, -0.315245, 0.486123, 0.0762495, 0.778554]
The maximum error is: 0.039, 7.274 percent.
The minimum error is: -0.021, -3.594 percent.
The maximum value is: 0.692.
power
Solution is:
[6453.3, -37890.7, 25363.6, 53377.2, -8663.05, 63310.3]
Convexity check, the numbers should be positive:
63633.9
5.79669e+008
The maximum error is: 2284.538, 12.808 percent.
The minimum error is: -2565.743, -1.092 percent.
The maximum value is: 234874.257.
```

9.6 5. Output of the program

The output has several parts, first it says rpm, then efficiency then power. The solution shows six numbers, these are the coefficients of the polynomial fit containing the coefficients of a polynomial

$$c_1 Q^2 + c_2 Q + c_3 H^2 + c_4 H + c_5 QH + c_6$$

starting with c_1 . In the following two lines the maximum and minimum error is given (with signs) in absolute value and percentage. Also the maximum value is given to make it easier to judge the errors.

The same type of output is given for the efficiency.

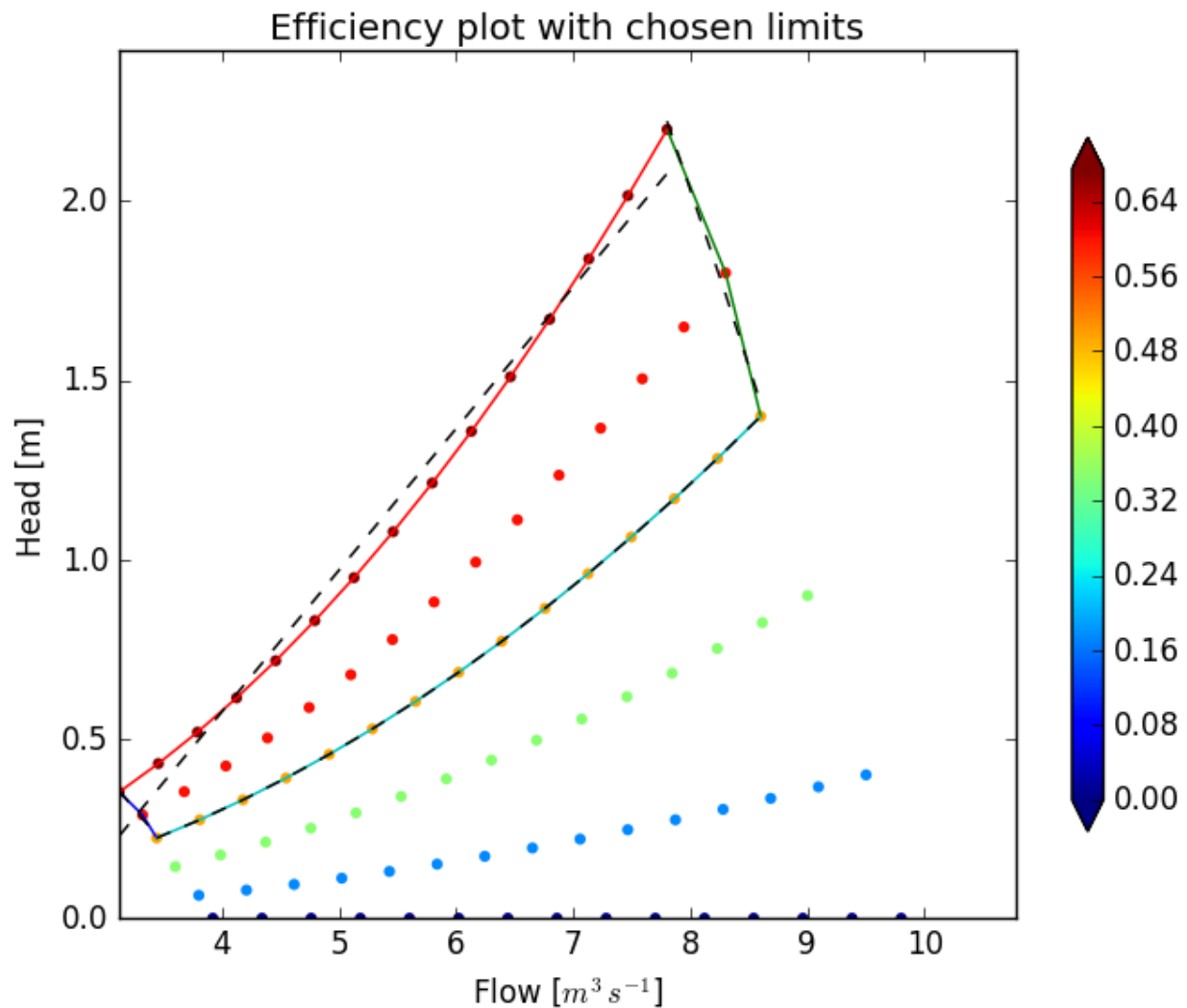
For the power the output is a bit longer. Briefly, the last lines should be read.

The other lines are showing the first approximation attempt of the power. It can be seen that the maximal error is 12 %. If the first attempt is not convex, the program does a second one ensuring convexity. This might result in bigger errors.

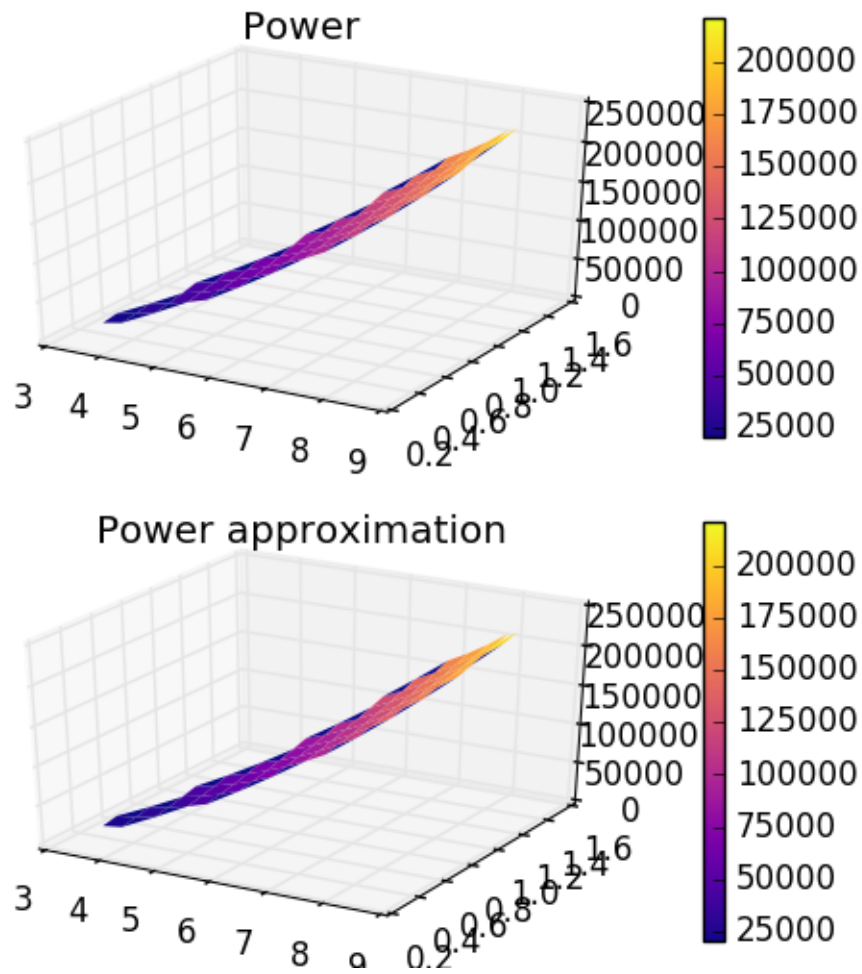
These coefficients are also stored in text files in a format suitable to copy them to the pump model. There are four text files created: `power.txt`, `speed.txt`, `working_area_fit.txt` and `efficiency.txt`. The latter is not strictly needed for the pump model.

9.7 5. Output figures

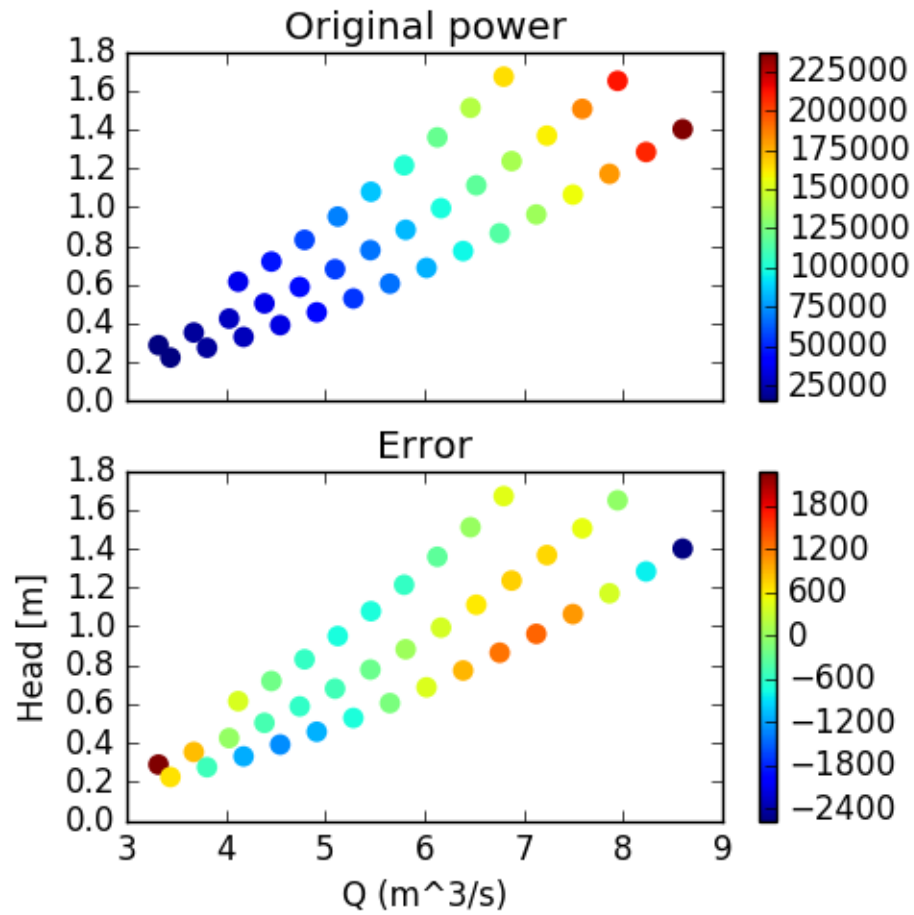
The plot called `EfficiencyWorkingArea` shows the calculated efficiency surface and the chosen boundaries of the working area. The colorful lines are the working area boundaries calculated from the data based on efficiency and rpm levels. However, they might not be convex. If they are not convex, they are replaced by convex approximation (black lines).



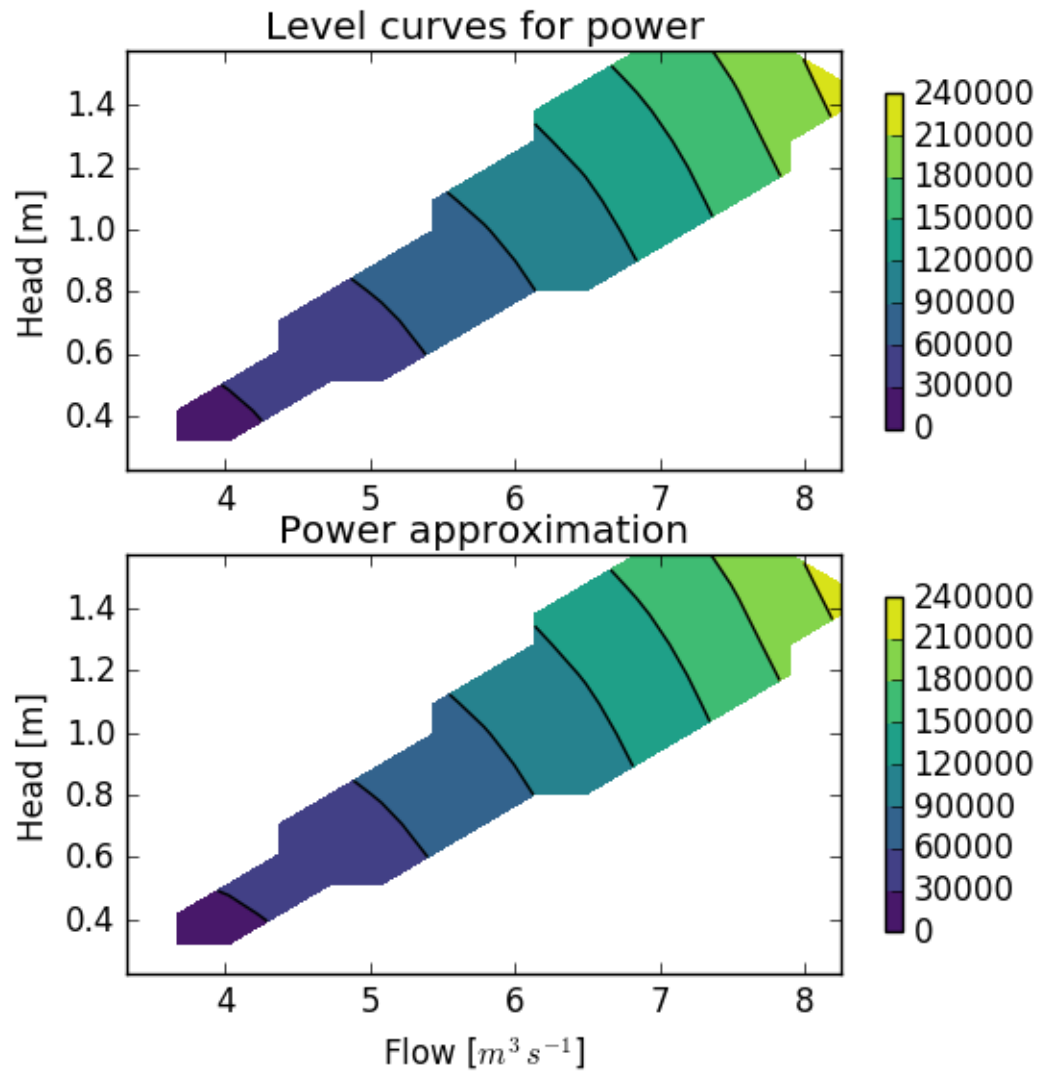
The plot called "surface" shows the original and the approximated power surface.



The plot called “powers and error” shows the original power and the error of the power approximation.



The plot called `LevCurvesApprox` shows the original and the approximated power as level curves.



And finally the plot called “Gradients” shows the gradient of the original and approximated power surface. It is important for the optimization that apart from having a small error the gradients also point the same direction.

