International Gas Union Research Conference 2011

MODELING OF BRANCHED CONFIGURATIONS OF COMPRESSOR STATIONS

Main Author

M. Haulis

Czech Republic

ABSTRACT

New technological advances in the area of compressor technology allow to build compressors with wider range of characteristics than in the past. This results in requirements for never before seen configurations of compressor stations, such as one powerful compressor in parallel to a branch of several smaller serial compressors. These new configurations pose new challenges for simulation and modelling as there are numerous ways of managing and coordination of units.

The paper talks about simulation and modeling of new configurations, namely so called “branched” configurations when coupled compressor / drive units are connected in several parallel “branches” within a compressor station. One such branch can consist of one or more serial machines. We have researched a way how to model the responses of such configurations to different type of setpoints as well as how to model different ways of distributing the load between the branches and between the individual machines in a branch.

In our simulation software (SIMONE) there are several types of setpoins – flow, suction pressure, discharge pressure, pressure ratio, revolutions, maximum operations. In order to model the response of compressor station using branched configurations to these setpoints, they have been grouped into two groups – one group that requires volumetric flow and adiabatic work point from a station and another group that requires the working point to be on a specific level of revolutions. We have come up with a way to see how the volumetric flow is distributed through individual branches depending on either the surge distance ratio in all machines being constant as well as ratio of revolutions of units being constant and equal to ratio of nominal revolutions.

The conclusions of the paper have implications in the area of design and operation of compressor stations mixing extremely different compressor types that can be used for these non-trivial configurations.

TABLE OF CONTENTS

PAPER

1. STANDARD COMPRESSOR STATIONS

Standard compressor stations in SIMONE software are modeled as a conglomerate of compressors, drives, coolers and resistances. It asks for the response of the compressor station to requirements as specified by the physical layout of the network and / or user wishes of how the compressor station should be simulated.

The coupled compressor and drive units (machines) are connected using a configuration to the overall compressor station configuration. This configuration can contain one or more machines per stage and one or more stages per compressor station (1). However, it was found that this standard compressor station solution cannot handle more complicated configurations, such as branch configuration.

There are two levels to standard compressor station processing:

- Compressor (machine) level, when the variables for individual compressors in the configuration are calculated
- Compressor station level, when the overall variables for compressor station are calculated when put together all machines in the configuration.

The compressor station always functions within the network model. The influence of the surrounding network results in certain degree of flexibility of the trajectory of possible working points in the compressor station. In this paper we call this "network flexibility".

2. BRANCH CONFIGURATION

New technological advances in the area of compressor technology allow to build compressors with wider range of characteristics than in the past. This results in requirements for never before seen configurations of compressor stations, such as one powerful compressor in parallel to a branch of several smaller serial compressors. These new configurations pose new challenges for simulation and modeling as there are numerous ways of managing and coordination of units.

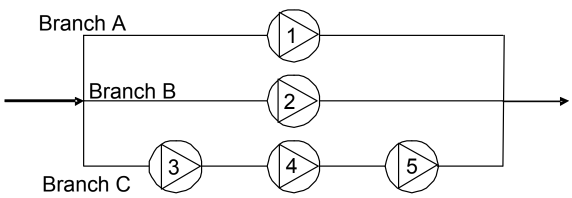

Figure 1. Sample branched configuration of a compressor station

In this paper we are using this sample branched configuration for calculation of sample tasks. For simplicity reasons, we assume machines 1 and 2 are of the same type as well as machines 3, 4 and 5 are of the same type. In order for the branch configuration to function properly, the machines used should be mutually compatible. This means the resulting adiabatic head (HAD) possibilities of each of the machines 1 and 2 within the normal working region should roughly equal the sum of HADs of machines 3, 4 and 5.

For testing purposes we used compressors with the working envelopes as follows:

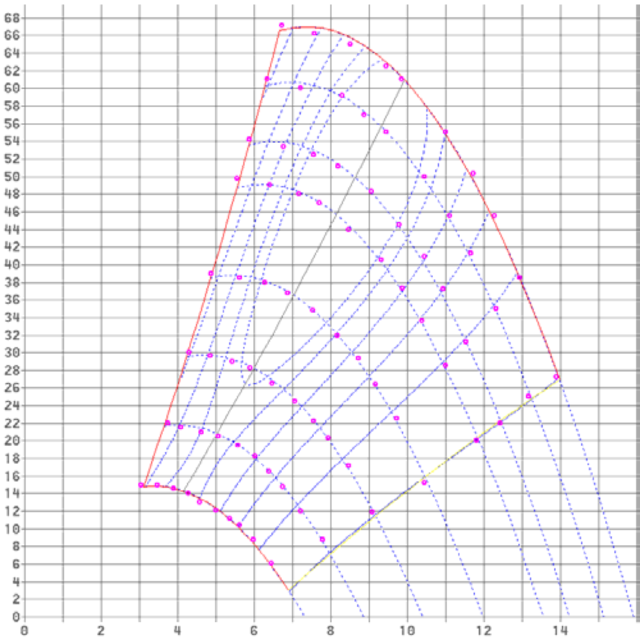

Figure 2. Sample compressors 1 and 2

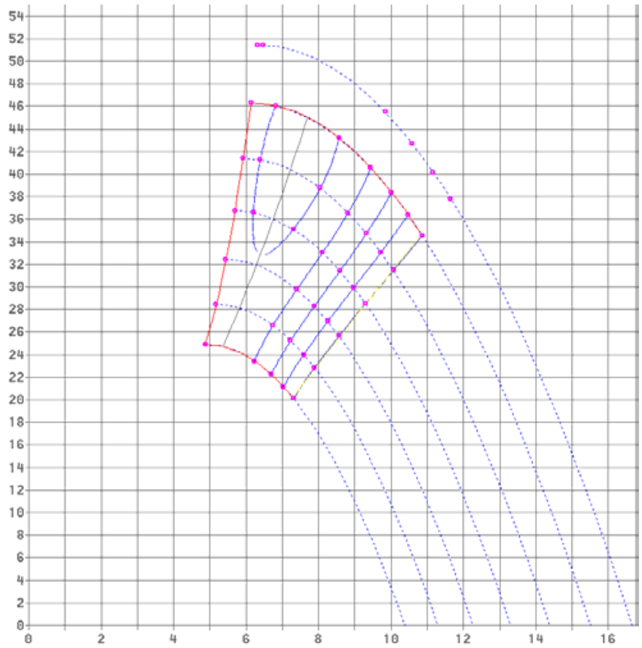

Figure 3. Sample compressors 3, 4 and 5

The working envelope is always defined in the coordinates HAD (Adiabatic Head in kJ/kg) and QVOL (Volumetric Flow in m^3/s), because these coordinates are invariant to inlet conditions. The points in the diagram represent measured couples of HAD / QVOL and the revolution lines are calculated by the SIMONE software.

We did not model any resistances or coolers for testing purposes, because our first task was to prove that the algorithm is working on the basic level. The algorithm we developed covers all possibilities of branched configuration. However, due to current limitation of software used, the implementation of the algorithm has the limits of maximum of five branches and maximum of five serial compressors per branch. We believe that this should cover any currently possible combinations of machines in branch configuration in any of networks that use our software.

3. SOFTWARE USED

To simulate the branched configurations, we have used our proprietary software (SIMONE) that is an industry-wide standard for simulation and optimization of gas networks. We have integrated the resulting algorithm into the software, so that the operationability of the algorithm could be proven by real life examples of branched configurations of compressor station.

In the software there are several types of setpoins to model the actual behaviour of operators of compressor station (2). In order to model the response of compressor station using branched configurations to these setpoints, we have grouped these setpoints into two groups

- **Gas related setpoints**. This group comprises of setpoints like flow, inlet pressure, discharge pressure and pressure ratio. These setpoints can be translated into the coordinates of adiabatic head and volumetric flow.

- **Revolution related setpoints**. This group contains setpoints like speed setpoint or relative speed setpoint. The requirement for this group can be translated into the coordinates of adiabatic head and volumetric flow using the flexibility of the network around the compressor station and the actual revolution curve of the compressors installed in the station.

Finding a solution differs for both of these groups and it is described in the following chapter of this paper. In addition to the different setpoints, the SIMONE software allows different ways of coordinating the operation of all the compressors installed in the compressor station. There are two ways of coordination currently implemented and they are:

- **Speed ratio**. This coordination law states that the ratio of revolutions installed in the compressor station is fixed to the value of ratio of nominal revolutions. This coordination law is upheld until a border of one machine is reached, then it is released.

- **Surge distance control**. This coordination law states that the relative surge distance in all the machines remains the same. It means that the distance of working point from the surge line measured on the line parallel with QVOL axis divided by the distance between minimum and maximum flow on the line parallel with QVOL axis running through the working point is the same for all installed machines.

The algorithm we have developed can cope with any combination of above mentioned setpoints and coordination law, thus it is robust enough to be used in all task types that are currently possible in the software (static simulation, transient simulation, reconstruction and others).

4. COMPRESSOR STATION RESPONSE

The basis of modeling branch configurations of compressor station is to model the response of compressor station to the conditions of the gas network surrounding the compressor station as well as the requirement regarding the operations of the compressor station represented in our understanding by the compressor station setpoint.

When considering the modeling options, we found out that we have to limit the degrees of freedom when splitting the resulting station working point into working points of individual machines in branches.

Because the suction and discharge nodes of each of the branches are connected and are, in fact the suction and discharge nodes of the compressor station as a whole, the physics dictates us that the HAD of each of the branches equals to the HAD of the compressor station as a whole. This finding limited our degrees of freedom to finding the way to split the required volumetric flow into each of the branch and then use current software solution to calculate the response of each of the branches as if it would be a standard, one branch compressor station.

When the working point of each of the branches is found, the rest of the variables (such as temperature, fuel consumption, power, etc.) for all the machines is calculated accordingly.

4.1 Gas Related Setpoints

The gas related setpoint, as defined above, sends a request to compressor station processing to model the response of the compressor station to the requirement. The algorithm differs for each of the setpoints, in relation to the position of the setpoint to the compressor station envelope.

The first question to be asked is whether the compressor station and each of its branches can fulfill the requested HAD. If they cannot, it has to be found whether the flexibility of the network around the compressor station allows to move the working point within the possibilities of the compressor station. If it does not, no feasible solution is found and the result is compressor station giving the required working point, but notifying the user that it is not within the physical limitations of the model.

Once the HAD is within the possibilities of the compressor station, the second question to ask is where does the working point lie compared to the overall envelope of a compressor station.

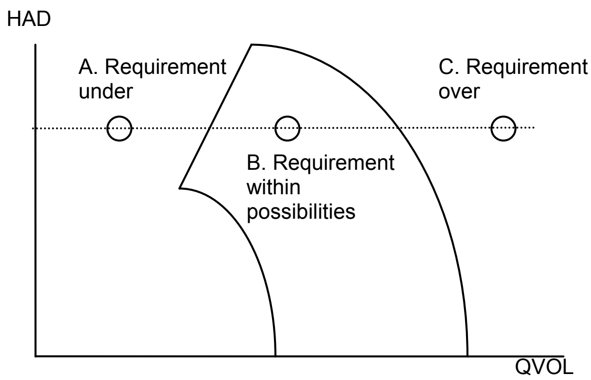

Figure 4. Position of the working point

When trying to calculate the compressor station envelope, we found out that there we could not find a way to calculate a mathematical approximation for the borders of this overall envelope. Therefore we construct these borders only around the line representing the same HAD for compressor station and for each of the branches. In Figure 4. this HAD is represented by the dotted line. The construction of the borders consists of iterating each branch and finding the minimum and maximum of the volumetric flow through each of the machines in the branch. The minimum and maximum flow through the first machine of the branch gives us the minimum and maximum of the branch and summing these give us the minimum and maximum of flow through the compressor station as a whole (because branches are parallel to each other).

The following picture illustrates finding of such borders, for our sample station. It casts various HAD's and finds the borders of the overall station always in the vicinity of the given HAD. It shows the envelope of a compressor station when the following conditions are in place:

- Ambient temperature = 12°C
- Inlet pressure = 51.01 bar
- Inlet temperature = 10°C
- Gas relative density = 0.60
- Pseudocritical pressure = 45 bar
- Pseudocritical temperature = 193.7 K
- Adiabatic exponent κ=1.38 (Simplified description of real gas behavior used in the examples (theorem of corresponding states and assumption of constant adiabatic exponent))

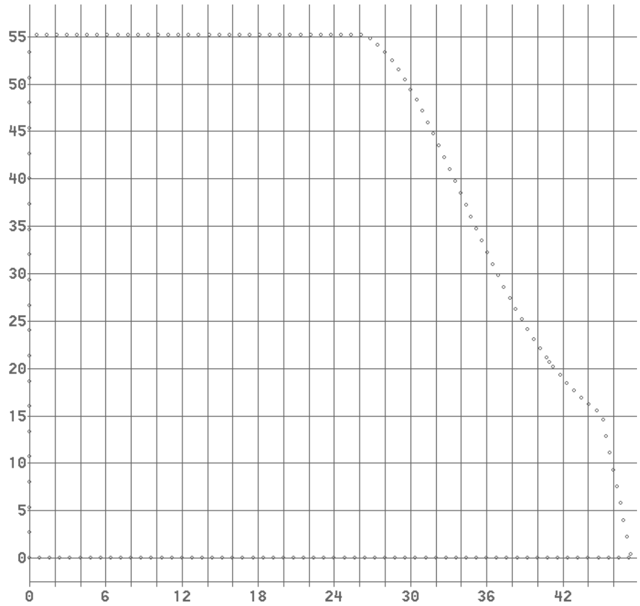

Figure 5. Sample borders of compressor station with branched configuration

The envelope in Figure 6 shows a situation full bypass allowed for the compressor station even under minimum revolutions. It does not show the surge line for the compressor station as a whole as it is constructed only during the calculation of individual machines for calculation purposes.

Now once we had the minimum and maximum through the station, we are able to define the processing of each individual working point position.

4.1.1 Requirement Under

If a requirement is under the minimum flow that the compressors can give, in reality a bypass valve would open, so that the compressors do not operate within the surge region. The bypass causes the flow through the compressor to increase, while retaining the low flow through the compressor station as a whole. So it moves the working point towards the surge line or minimum revolutions line in parallel to QVOL axis.

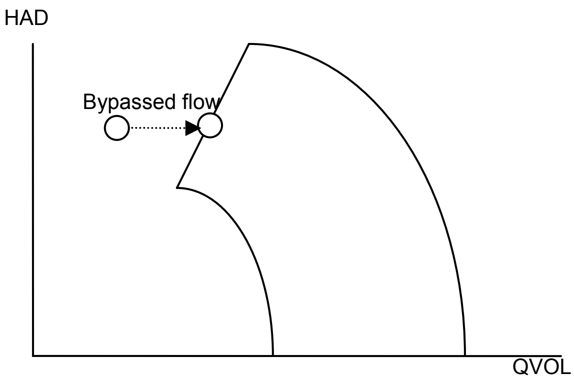

Figure 6. Requirement under

4.1.2 Requirement Wthin Possibilities

If a requirement is within the possibilities of the compressor station, the resulting flow must be divided between branches according to the coordination law.

4.1.2.1 Speed Control

For speed control coordination, one of the branches is used as a master and the rest of the branches and machines are calculated as if they had their revolutions given by the fixed to the master. The region between minimum and maximum possibilities is split into a specified number of tries and then the resulting flow through the whole station is compared to the required flow. The flow through the whole compressor station resulting from master revolutions that is the nearest to the requirement is proclaimed as the correct one and the rest of the branches are calculated accordingly.

This approach is used because the dependency of volumetric flow and revolutions does not always have to be monotonous for the whole compressor station. If the algorithm cannot find the result, it falls back to the Surge distance rule and the user is notified.

4.1.2.2 Surge Distance Control

For surge distance, the matrix of equations is constructed and solved, so that the surge distance for each of the branches and consequently for each of the machines remains the same. This approach gives solution in the whole region of compressor station possibilities.

4.1.3 Requirement Over

If a requirement is over the maximum flow that the compressors can give on a given HAD, the software needs to model the response of compressor station based on the physics within the surrounding network. Therefore a network flexibility is used and a solution within the characteristics is found (3).

If the network does not allow to do this, no feasible solution is found and the result is compressor station giving the required working point, but notifying the user that it is not within the physical limitations of the model.

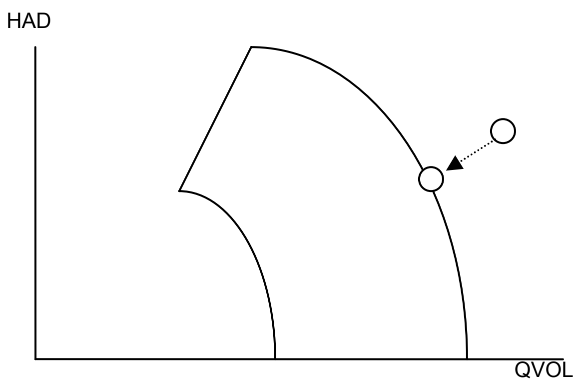

Figure 7. Requirement over

4.2 Revolution Related Setpoints

For revolution related setpoint the required working point is moved in the same way as if the requirement is over for gas related setpoints. However, if the setpoint specifies the revolutions different from maximum revolution, the compressor station diagram is adjusted to reflect this requirement.

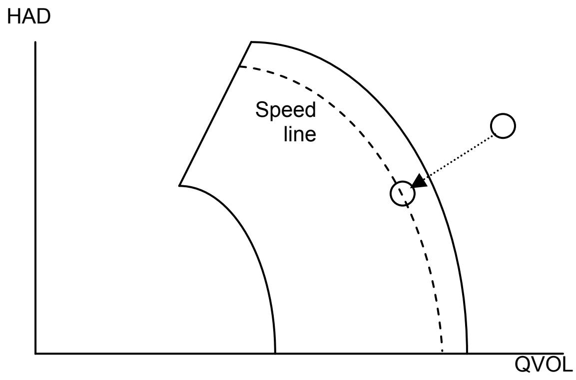

Figure 8. Revolutions related setpoints

5. PRACTICAL CALCULATION

This chapter contains some practical examples of calculation with the algorithm that was developed to model the branched configurations of compressor stations. We used steady state calculation, because the way how the overall compressor station picture is constructed does not allow to display the trajectory of working point within this picture for dynamic simulations. However, the dynamic simulations display the trajectory of the working point within each of the machines.

We only calculated working point within possibilities and under possibilities for purposes of this paper, because to correctly model the working point over possibilities, one would have to describe also the topology and behaviour of network surrounding the compressor station. And such description is outside the scope of this paper.

5.1 Working Point Within Possibilities – Surge Distance Coordination

For this example, we requested surge distance coordination and a working point of

- QVOL = 24 m^3/s
- HAD = 40 kJ/kg

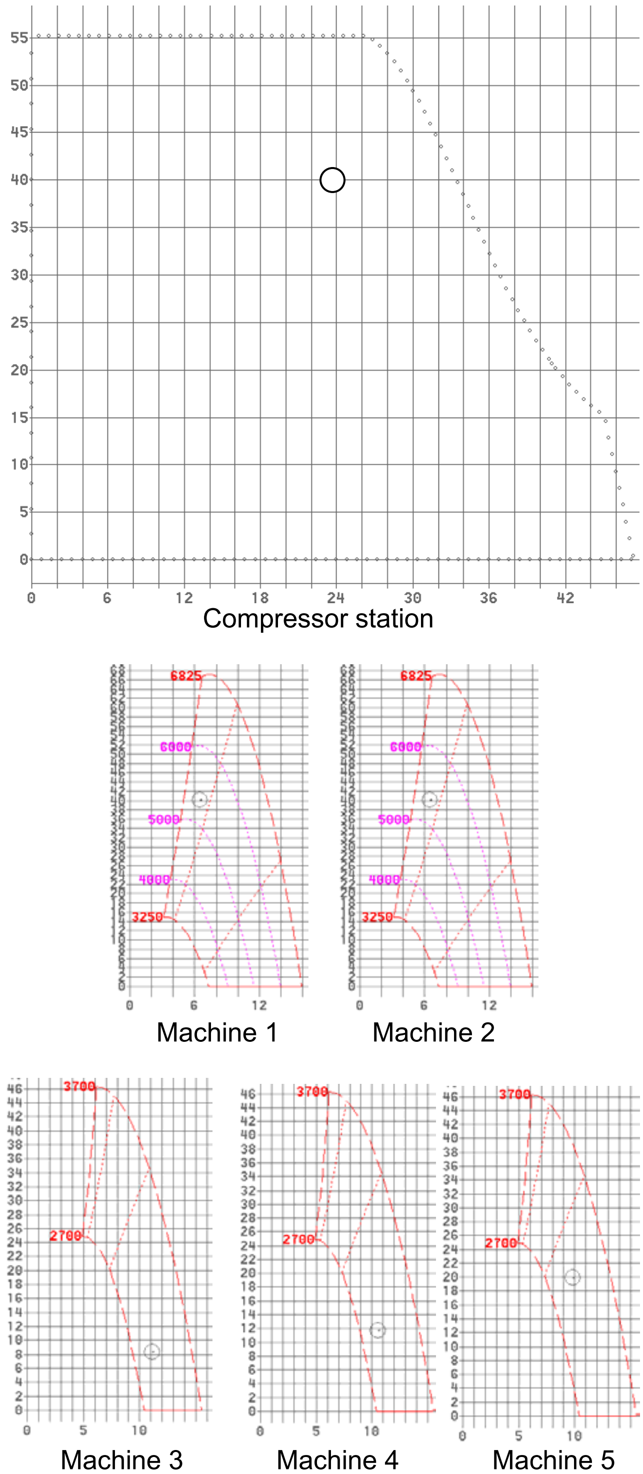

Figure 9. Working point within possibilites – SD control

5.2 Working Point Within Possibilities – Speed Control Coordination

For this example, we requested speed control coordination and a working point of

- QVOL = 30 m^3/s
- HAD = 40 kJ/kg

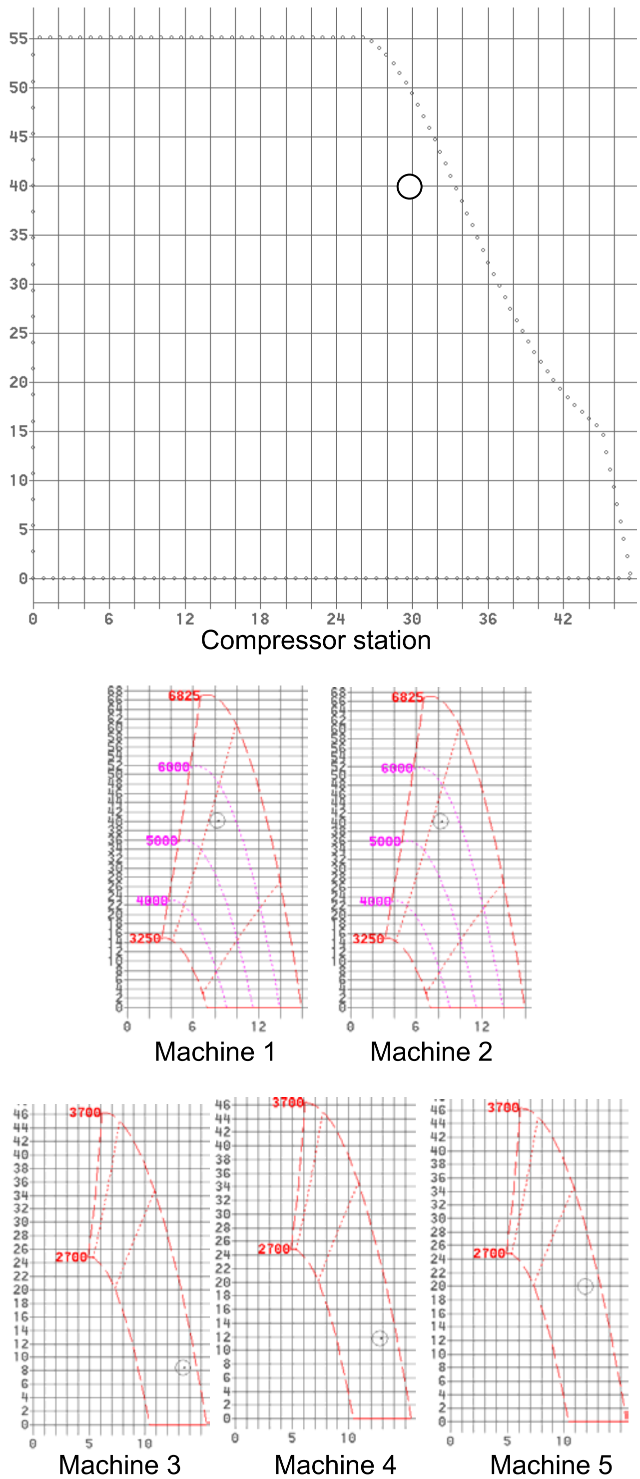

Figure 10. Working point within possibilites – speed control

5.3 Working Point Under Possibilities

For this example, we requested a working point of

- QVOL = 6 m^3/s
- HAD = 40 kJ/kg

The coordination law is not relevant, as the working point is not within the possibilities. So the calculation is the same for both coordination laws.

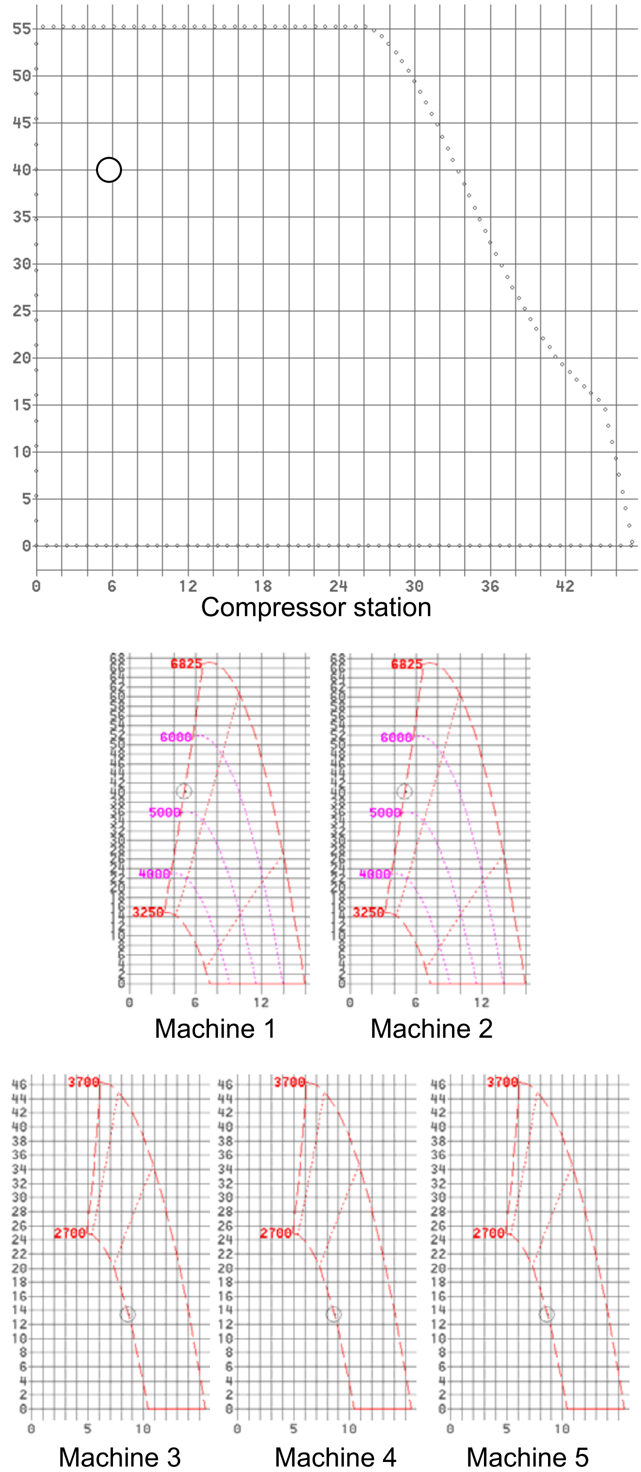

Figure 11. Working point under possibilites

6. CONCLUSIONS

In conclusion we have developed a robust algorithm of how to solve non-trivial configurations of compressor stations. These solutions can be used by the users of our software to model the response of complicated compressor stations.

Also, our algorithm can be used to verify whether the configuration proposed is feasible by calculating the overall working field of branched configuration compressor station. This verification can be then used in design and development of compressor stations with mixed technology, so that these assets are used efficiently.

The options of the algorithm allow modeling of various modes of operation and give the users flexibility of choosing the preferences they like.

Last, but not least, the integration of the algorithm within the SIMONE package is a powerful tool for gas companies that for one reason or another need to build these complicated configurations for their compressor station.

REFERENCES

1. Jenicek, T., Kralik, J., 1995, “Optimized Control of Generalized Compressor Station,”, Pipeline Simulation Interest Group, PSIG, (1995) , PSIG '95
2. Kralik, J., Stiegler, P., Vostry Z., Zavorka, J.: “Dynamic Modeling of Large-Scale Networks with Application to Gas Distribution”, Academia Prague, 1988
3. Jenicek T., Sterba J., Kralik J., Vostry Z., Zaworka J.: Textbook on Dynamic Simulation of Gas Pipeline Networks, LIWACOM, Essen, 1991

LIST OF FIGURES