Integrated Test Systems with hot gas generator for the
development of turbocharger applications

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Abstract: The requirements of the turbocharger developer with regard to the development tool „hot gas test rig” are due to multiple development goals and tasks increasingly complex and comprehensive. The requirements that encapsulate this development environment will be formulated by a turbocharger developer. These same requirements are then used by KRATZER AUTOMATION to visualise the solution and plan future development. The combined goal is to provide the developer with a tool that may be used to analyse the operational- and load focus of the turbocharger. The Hot gas test rigs can simulate the presence of a combustion engine. This simulation provides a development and test environment whereby the temperature and mass flow rates of the combustion engine are replicated. The KRATZER AUTOMATION ATL – test rig is comprised of a basis system which may be modularly extended. Further light will be shed upon this flexible and automated test bench solution. The benefits that this solution provides to developers and the resulting increase in performance will also be expanded upon. Ultimately the test rig is to be viewed as a not just an isolated tool, instead due to its ability to run various tests automatically, it is to be integrated into the entire development process.

Key-Words: Hot gas test bench, Turbo Charger development, Turbo Charger application, Application test bench, turbocharger, performance, MHI, KRATZER AG

1. Introduction
The selection of turbochargers for combustion engines is based upon the characteristic maps of the supplier. These maps are measured in ideal up- and downstream conditions. In the future the systems development will be better designed and more compact. This means for example that the turbine house will include the manifold. The map measuring to guarantee the correct selection of a turbocharger must take this evolution into account.
The following section comprises a description of the current and future demands that are placed upon turbochargers. This description has been composed by a turbocharger developer, and on the basis of this description the test bench tools will be introduced.

2. Introduction MHI Turbocharger testing
Mitsubishi Heavy industries develops and produces industrial products varying from ocean going vessels, power plants, gas turbines, household air-conditioning units up to turbochargers. The technology for these products is developed on a fundamental level in 5 main development centres. The application of the technology takes place in market dedicated offices and factories. Such as MHI Equipment Europe BV (MEE), which develops and produces automotive turbochargers for the European market.

For the fundamental development of turbocharger technology, job dedicated test benches are often used which only to test specific components such as bearings or turbine wheels. The application test
benches concentrate on the behaviour of the complete customer configuration turbocharger. In MEE such an application test bench is being installed. It will be used for measurement as well as destructive testing according to MHI and customer specific testing protocols. For this a highly flexible bench is required which allows many different set-ups and has a high automation degree to guarantee the reproducibility of tests.

By automation of the test cycles unmanned testing leaves the operator free to prepare the next test and enables a high occupation range of the equipment, as 24hr testing is possible. This will however put high demands on the installed safeties.

2.1 Turbocharger performance measuring

For the measurement of performance maps only general standards are available such as SAE J922 [1], SAE J1826 [2] and ISO5389 [3], which describe basic measuring and calculation techniques. Turbocharger manufacturers have developed their own specific measuring methods, which results in a difficult comparison between maps of different suppliers and different measurement locations. For engine simulation programs it is often difficult to correct for these differences. Due to this, engine manufactures have often their own specific requirements for compressor and turbine maps.

An application test bench should be able to deliver measurement results according to the different methods.

2.1.1 Compressor performance

The main differences between compressor maps are caused by different data calculations and representations, different test criteria and different measurement setups.

As map generation from test data can be automated it is possible to deliver the measurement results in many desired formats for pressure ratio, flow and efficiency.

Measurement methods such as the number of speed lines and measuring points can be varied by using different programs of an automated bench.

Measurement criteria for surge and choke have to be set to fully automate the test and achieving proper correlation between different MHI benches. This is also achieved by using a standardized layout of the measurement tubes and sensors. When customer piping is used the influence on compressor behavior can be investigated.

2.1.2 Turbine performance

Besides the differences in setup and calculation methods, two different measurement techniques are commonly used for turbine map measurement: including or excluding turbine heat loss.

When including heat loss, the turbine performance is measured at an inlet temperature of around 600 °C. The resulting map gives a good representation of actual “in vehicle” performance. Because the actual heat loss in vehicle is determined by under bonnet conditions, heat shielding etc., a difference will always remain. Also temperature probes in the gas stream can be influenced by the heat radiation from the walls. The method excluding heat loss measures at low inlet temperatures around 100°C with an exhaust temperature near room temperature and with insulated turbine housing. The efficiency will be the maximum achievable. However in calculations a correction factor for actual heat loss has to be included.

2.1.3 Closed loop equipment

Loading the compressor absorbs the delivered turbine power.

To be able to measure according to both methods a wide range burner is required.
The temperature rise in the compressor is amongst others depending on pressure ratio and compressor efficiency. Throttling the compressor will increase the absorbed power as the resulting pressure and temperature rise is bigger then the decreased mass flow.

The compressor loading is limited by over speed, surge and shock. When reaching compressor surge, increasing the mass flow can only increase the absorbed power.

Changing the compressor size will change the mass flow. However for a turbocharger in customer configuration this is not a practical solution. When the compressor is operated in a closed loop system the mass flow can be adjusted by varying the pressure in the closed loop.

The control parameters of the closed loop can be derived from the measured compressor map and integrated into the automation for measuring the turbine map.

2.2 Validation testing

During application development several tests are performed for charger validation such as:

- Bearing validation with customer oil conditions.
- Burst containment testing of compressor and turbine housing.
- Over speed validation of turbine and compressor wheel.
- Thermo shock testing of turbine housing
- Foreign object impact validation of the wheels

The diversity and frequency of these tests do not justify a different bench for every test. By using a flexible and quick setup of equipment and automation of the different protocols, it is possible to perform these tests with one single bench.

To guarantee product quality over the life cycle of the turbocharger, some of the validation test can be re-occurring. For example repeating the destructive test can check welding or casting quality. Automation of test cycle and conditioning will guarantee reproducibility of testing conditions.

Integrated manifolds pose a challenge for mounting on a single burner outlet, especially when thermal cycle test are performed. In this case both test specimen and mounting adapter are subject to the thermal loading. Water-cooling of the adapter can be applied to reduce wear but reduces the turbine inlet temperature.

2.3 Future upgrades

Current gasoline engines operate at a turbine inlet temperature of around 1000°C, A max continuous burner temperature of 1100°C will be sufficient for testing the current generation of chargers. As temperature will increase in future engines, reservations have to be made to upgrade the installation accordingly.

Environmental regulations demand more complex exhaust systems for after treatment. Especially with diesel applications the application of particle filters results in a higher exhaust backpressure and turbine inlet pressure. These pressures will even increase more when two stage (sequential) systems are applied. Validation tests at these high pressures require higher burner pressures than used for current charger tests.

Figure 3; Twin thermal shock layout

Current layout for thermal shock tests is with one single turbocharger. During the cooling cycle the burner is switched off and cold air is by-passed to the charger. When using two turbochargers the hot and cold gas is switched between the two chargers. The advantages are shorter test times when more chargers have to be tested and less cyclic thermal loading of the burner unit. This will not be the case for the switching unit however. Reservations will be made in the installation for amongst others the higher required compressed air flows and double oil and water flow for the bearings.

In view of simultaneous engineering the simulation of the gas cycle of engine becomes more and more interesting for the developer. With this in mind the design and layout of a unit, which provides the pressure pulses caused by the engine gas cycle, will be the challenge for the future.
3. Integrated hot gas test bench

3.1 Introduction

KRATZER AUTOMATION AG is an innovative software company specialized in industrial applications in the fields of development, production and logistic. The headquarter is located in Munich/Germany. The division 'Test Systems' is a supplier of turn key solution for test systems in the field of research and development. The activities are geared towards the software of the processes. Based on a powerful automation system, the division 'Test Systems' supplies adopted solutions, which support the development process optimal. The activities are growing world wide. The projects for the Asian market are operated out of Shanghai (KRATZER AUTOMATION (Shanghai) Co., Ltd.)

3.2 General tasks

The main tasks of hot gas test rigs can be formulated as following:
- Measuring characteristic maps of turbine and compressor in developing set up as well as in application set up
- Stability research of thermo mechanical behavior
- Endurance test of all components such as bearing house, compressor and turbine wheel, etc.
- Dynamic behavior research of load capacities

On this main items, there are several more underlined test items, however which are a modification of the above mentioned tasks.

3.3 General system components

The hot gas test bench is based on natural gas. This is due to the wide operation range of this gas and its high accuracy of temperature distribution as well as the rotation free flow. This basic lay out is common in almost all research and development fields for turbochargers. Later on, the test rig demands a defined and stable compressed air input from 6 bar up to 8 bar (abs).

As an example, the main data of a turbocharger test rig, which is designed to test turbochargers for passenger cars, will be described in detail.

In consideration of the future demands in relation to:
- Higher temperatures for fuel applications
- Higher back pressure for two stage charging systems

The main data are made up of the following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot gas mass flow</td>
<td>kg/s</td>
<td>0.008</td>
</tr>
<tr>
<td>Burner range</td>
<td>kW</td>
<td>330</td>
</tr>
<tr>
<td>Hot gas temperature</td>
<td>°C</td>
<td>150</td>
</tr>
<tr>
<td>Hot gas pressure</td>
<td>bar (abs)</td>
<td>1.0</td>
</tr>
<tr>
<td>Hot gas temperature fluctuations</td>
<td>°C</td>
<td>+ / - 8</td>
</tr>
<tr>
<td>Automation System</td>
<td>PAtools TX</td>
<td></td>
</tr>
</tbody>
</table>

The main hot gas data: pressure, temperature and mass flow depends of each other. Their extreme values are not reached at the same time. The user can choose operation points like shown in the following figure (for 1 bar abs). At higher levels of hot gas pressure the operating field will be smaller in the under section, because there are physical boundaries which limit the burner function (for instance: flame stability, flame control, heat transfer)

According to this main data the developer will find a characteristic field in which he can set his operation points. These operational points are freely adjustable:

![characteristic map of hot gas generator (1 bar (abs))](image)

The mass flow of hot gas is provided over high temperature flange to feed into the measurement pipes, this is used for the characteristic map measurement of the turbocharger it self. Besides the hot gas generator there are several more pieces of equipment which are required to measure characteristic maps. These system components are as follows:

- Back pressure unit to adjust the correct mass flow of the TC compressor
- Oil conditioning unit to adjust a stable input pressure and input temperature for the TC bearing
- Water conditioning unit to adjust a stable water input temperature for water cooled bearing housings

The following scheme provides an overview of the system components:

![System components diagram](image)

**figure 5: System components**

The focus of this layout is to provide a compact system which comprises all the units needed to provide the media connection directly at the process of the test object.

**3.4 Electrical heater**

In order to reach a higher operation field in lower temperature regions, the system is equipped with an electrical heater which covers the range from 0 kW up to 8 kW, which is the. The range of electrical heater and the minimum burner capacity have a certain overlap.

![Electrical heater in bypass diagram](image)

**figure 7: electrical heater in bypass**

The mass flow of the electrical heater is by-passed into the combustion chamber and is switched automatically to the main mass flow according to the temperature demand at the in- or output channel of the turbine. Additionally the by-pass is also used for thermo shock research.

The electrical heater provides the possibility to measure characteristic maps of turbines in lower temperature conditions according to the following characteristic map.
The handling of the burner power and the electrical power is automatically controlled by the automation system. This results in stable temperature conditions at the input of the turbine over a wide range of mass flow in the dynamic of maximum 1:40.

### 3.5 Integrated closed loop system

In the closed loop the compressor output is traced back to the input of the compressor. To get higher pressure levels in this loop, there is a connection to a compressed air supply. By means of this, the pressure level of the loop can be adjusted.

The following parameters are controlled in this loop:

- Input temperature of compressor
- Input pressure of compressor
- Intermediate pressure in the loop

Corresponding to this target point, the operator has several possible test items. The main items are two stage charging and the measuring of turbine maps with a wide operation range.

#### 3.5.1 Two stage charging

A compressor in the second stage will have a different characteristic map than in ambient conditioning. These maps can only be measured with a defined compressor input pressure, this is provided by closed loop.

#### 3.5.2 Wide operation range

The boarders of the turbine map are normally restricted by the surge line of the compressor. To reach the requirement of highly independent measuring of the turbine from the compressor, the closed loop provides the possibility to shift the surge line within a certain range. The control parameters will be read out from the compressor map and handled automatically in the automation system in order to measure the wide turbine map.

### 3.5.3 Packaging

In order to provide a flexible and fast set up of different test items, the closed loop is mounted under the combustion chamber. The operator connects two flanges (compressor outlet and compressor inlet) to run the closed loop. The measurement equipment for pressure and temperature will be used in the same way as measurements in open loops.

The packaging is geared towards a compact design:

![figure 9: packaging closed loop](image)

Advantageously such a package should be installed in a test cell with double floor where the closed loop unit is installed in the lower level.

### 3.6 Dynamic hot gas mass flow

For the fundamental development of turbocharger applications it is necessary to analyze the thermo mechanical stability of the complete exhaust gas system. This results in the combination of manifold, turbine and exhaust gas pipe in one application. Typically this test will be run on engine test benches. Due to the fact that the operation cost of the engine test bench will be about double that of a combustion chamber test rig, it is reasonable to run this test item on the combustion chamber. Further more in case of simultaneous engineering the engine does not exist during the developing process. European test cycle for exhaust gas systems demands a dynamic behavior of mass flow and temperature and have also high requirements regarding temperature behavior. Overshooting have to prevent assuredly. To answer this requirement KRATZER AUTOMATION has achieved good results with temperature control loops.
based on Fuzzy – Logic. In the following diagram the
temperature control behaviour is shown as step respond.

![Figure 10: step respond temperature control](image)

3.7 Integrated test system.

3.7.1 Automation system

The automation system for control and regulation of the facility must tackle multiple tasks. KRATZER AUTOMATION provides its solution based on the automation system PAtools TX. The system was developed with the specific goal of deployment in research and development fields. It combines a self sufficient real-time system for control, regulation and data acquisition in combination with the well known handling features of a Windows operating system. The fundamental test tasks are available as pre-prepared test types, these must be parameterised. This parameterisation consists of setting the relevant nominal value.

3.7.2 Test sequences

The standards test sequences, such as characteristic map measurement needs the following parameter form the test engineer:

- circumferential speed line or shaft speed line
- temperature of hot gas
- number of reading point

The characteristic map based e.g. on 6 speed lines and 8 reading points requires in ideal conditions between three and four hours. The concept of flexible combination of test sequences enables the test engineer to perform his own sequences.

3.7.3 Test data management

The test results are the foundation of all other further calculation and simulation and will be therefore a very valuable basis for the development process of the turbocharger. In order to ensure the long term availability of this data, the test data management solution testXplorer has been developed. This tool provides a means of administrating the test results and other relevant test information. The tool based test data management solution consists of a basis module which organises the data and the repository in bulk storage devices. Also included in this basis module are for example production data acquisition and a scheduling/planning function for the test benches reason the testXplorer is suitable for individual process support in various test activities.

4. Conclusion

For turbocharger application development and validation testing a wide range of test are required. For this MHI will install a new hot gas bench supplied by KRATZER AUTOMATION AG. The design focuses on a flexible setup, high-test automation and automatic results generation. For a wide operation range, it will combine an electrical heater, a gas fired burner and a compressor closed loop installation when measuring turbine performance. Besides performance measurement also thermal fatigue cycles, over speed and burst containment tests can be performed with the same equipment.

References:

[2] SAE J1826, APR89, Turbocharger gas stand test code,