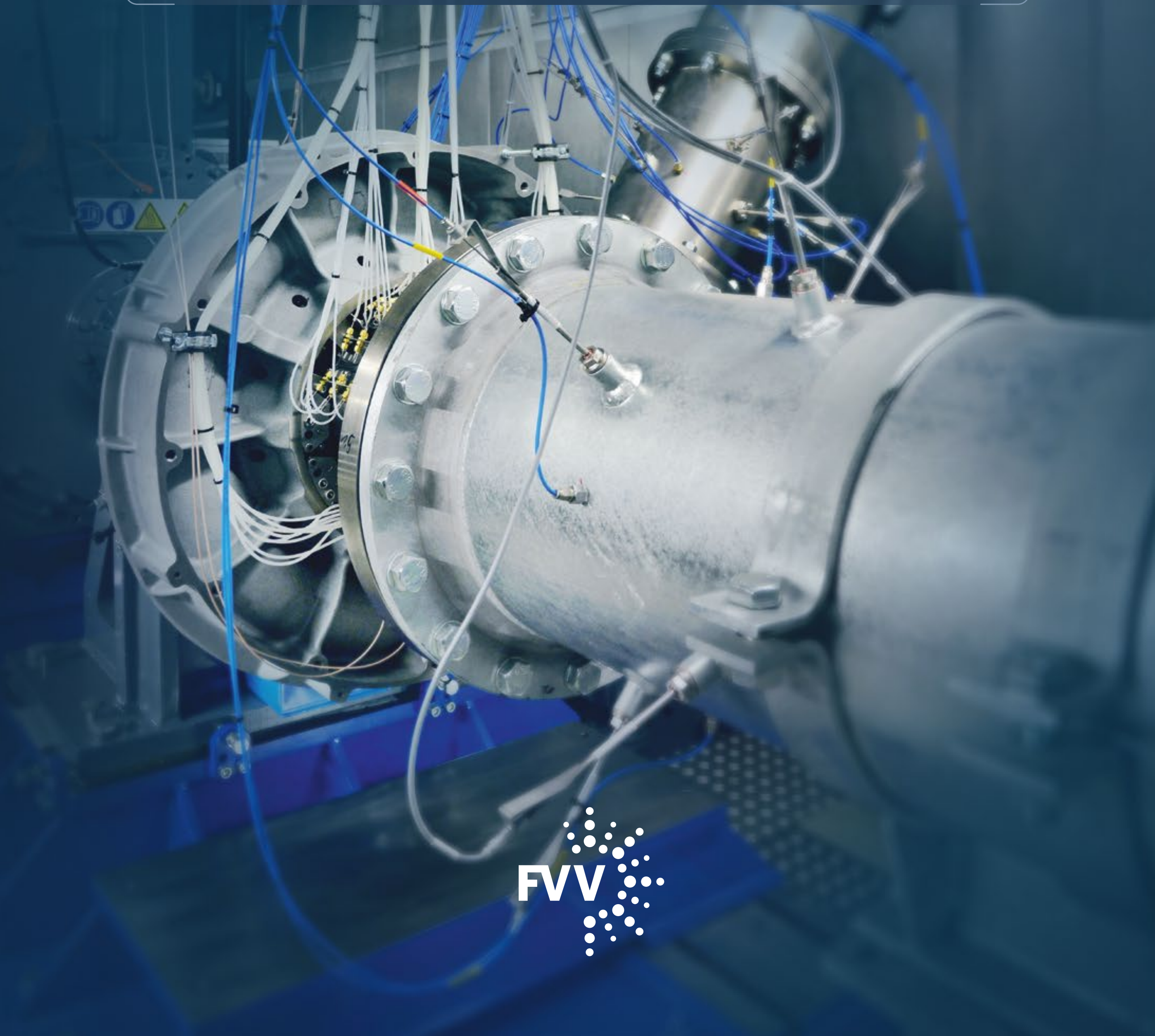
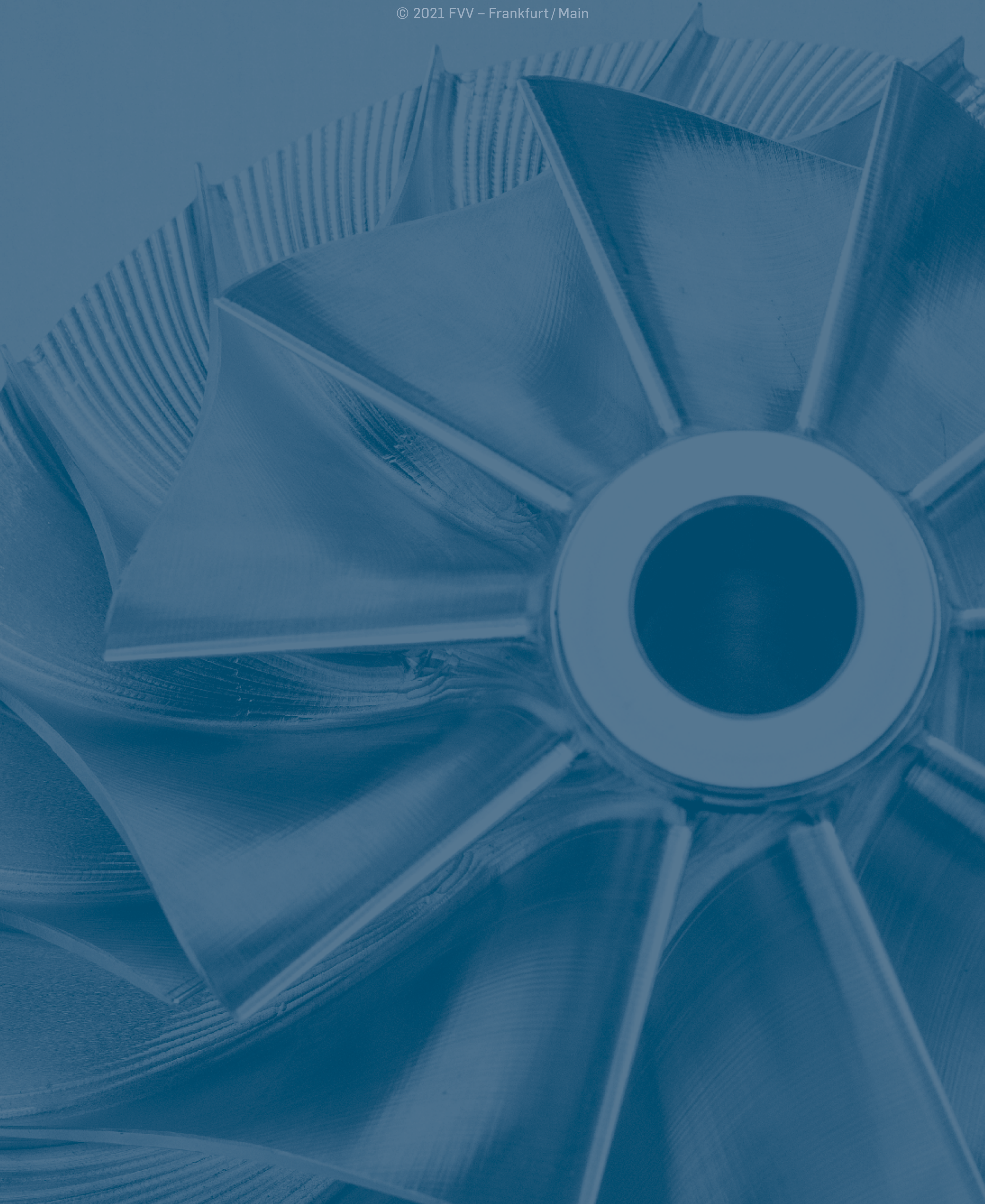
FVV PRIME MOVERS. TECHNOLOGIES.

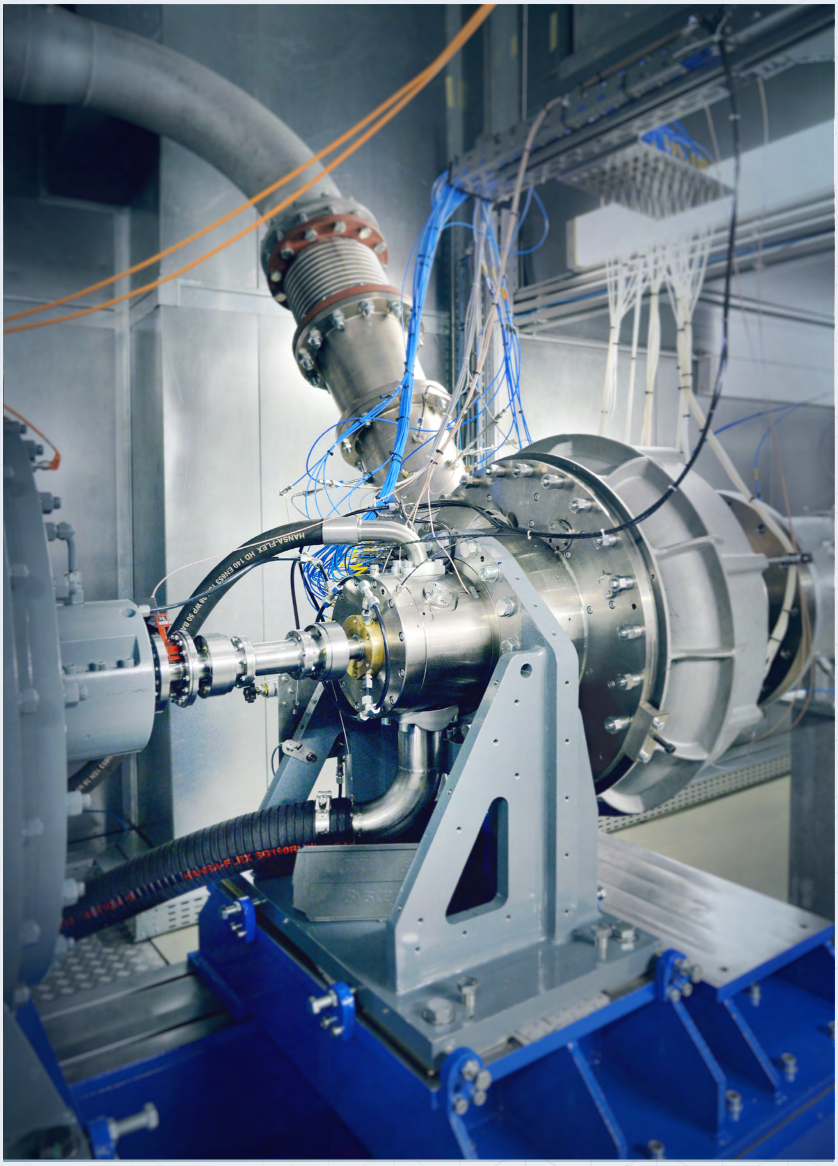
1968 – 2021
Centrifugal Compressor Research

Research projects of the past ten years



FVV





»Conducting experiments is the only way to calibrate, trim and verify your calculations.«

Prof. Peter Jeschke, Head of IST at RWTH Aachen University

»As in many other areas of the mechanical and plant engineering industry, Europe is also a global **technological leader in industrial centrifugal compressors**«

»Turbocharging progress«

Some machines are hidden away so well that they are barely noticed by the public – despite playing a decisive role in the progress of an industrialized society. This is the fate of the centrifugal compressor, at least when we consider compressors other than those used as »turbos« in modern combustion engines. Even for laypeople, it is immediately logical that gases need to be brought to a higher pressure level if they are to be used in industrial processes – irrespective of whether they happen to be in chemical plants or metal processing. Certain analogies to turbochargers in vehicle engines are absolutely legitimate: a higher pressure means that the subsequent process can be performed more efficiently, resulting in lower energy consumption and a lesser impact on the environment.

As in many other areas of the mechanical and plant engineering industry, Europe is also a global technological leader in industrial centrifugal compressors. European manufacturers and suppliers export their units throughout the entire world. When synthetic fuels are produced in Chile using wind energy, it is highly likely that the compressors used were developed and perhaps even manufactured here. However, leading positions also have to be defended. Industrial Collective Research is a proven instrument that lays the groundwork for this. The Centrifugal Compressor Research expert group founded within FVV more than 50 years ago successfully coordinates this collective research.

Technical progress has shifted the focuses of research time and again. Whereas early research concentrated on very fundamental issues relating to geometry, flow patterns and efficiency, today optimisation in a wide operating range and for intermittent operation is an important topic. As such, the research initiated by the working group is laying an important foundation for an industrial country that is switching its energy supply to renewable sources.

DR.-ING.
DIRK HILBERG
Deputy Chairman of the Scientific Advisory Committee / Chairman of Turbomachinery Research
FVV

DIPL.-ING.
DIETMAR GOERICKE
Managing Director
FVV

The FVV test rig commissioned at RWTH Aachen University in 2016 is an ideal instrument for collective research in industrial centrifugal compressors. For a supply industry dominated by small and medium-sized enterprises in particular, its benefit can scarcely be overstated: very few large companies can afford comparable facilities on their own. You will find out more about the results gained on the test bench to date on the following pages.

We would like to take this opportunity to thank all former and active members of the working group, in particular its heads, Dr Karl-Heinz Rohne (until December 2015) and Dr Matthias Schleer, as well as the RTD performers involved and our long-standing funding bodies. Your dedicated, collaborative work has turbocharged progress!

Frankfurt/M. | November 2021

It’s not something you have in the basement

Industry and scientists have been working together to research centrifugal compressors for more than five decades. In an interview, Dr Matthias Schleer, head of the Centrifugal Compressor Research expert group and Director R&D at Howden Turbo, and Dirk Bösel, Project Manager at FVV, talk about the importance of radial compressors and future research priorities.

Why is FVV conducting research into centrifugal compressors?

Bösel: Centrifugal compressors are always used when it comes to conveying gases or bringing them to a higher pressure. This is necessary in chemical processes or in pipelines in which gas needs to be transported over large distances, for example. Centrifugal compressors also allow air to be fed to combustion processes in boilers and gas to fuel cells. Turbochargers are another area of application, and these range from small cars to large ship engines. The applications will change in the future, but from a technical standpoint we will not be able to replace centrifugal compressors.

Schleer: Compressor systems are also needed for the production of renewable fuels. And in the raw materials sector we are seeing massive demand for industrial compressors, be it in the copper smelting plants that produce the materials for electric motors or in the extraction of lithium, which is needed for batteries. Therefore, one focus of the expert group lies in aligning research more strongly towards larger industrial compressors and further increasing their efficiency.

But is the efficiency really so important when in some cases the compressors and turbines of the energy system of the future will be started up and shut down several times a day?

Schleer: It is important to remember that even the smallest increase in efficiency can save a huge amount of energy – and CO_2, if you’re working with fossil fuels – over the service life of a 5-megawatt machine. Of course, flexible operation will simultaneously become more important at the same time. Therefore, instead of focussing on peak power, the whole of the operating range is taken into consideration during development so that energy consumption is optimised at as many operating points as possible.

Aside from efficiency, in which areas do you still see potential for optimisation in centrifugal compressors?

Schleer: Additive manufacturing methods will increasingly come into use over the coming ten years, and these allow highly complex geometries to be realised. This is certainly a new research focus. Material sciences will increasingly move into the limelight, as the compressor wheels are often subjected to loads right up to their yield point. But control will also become more important: how do we get a machine into the secondary operating points, what is the best way to set it up? These are just some of the topics that can be investigated at the centrifugal compressor test bench in Aachen in the near future.

What is the value of the FVV-funded test rig for centrifugal compressor research at RWTH Aachen University?

Schleer: There are not many of these test benches with large drive motors and such sophisticated instrumentation worldwide. The test bench in Aachen is certainly one of the largest that can be operated with around a megawatt of electric drive power. The advantage of this size is that it can be equipped with lots of measuring points and an extremely large number of sensors.

Bösel: A test bench like this is not something you have in the basement. Although there are a few large companies that can also invest in this technology, it needs to be provided for small and medium-sized enterprises, suppliers or CFD tool developers. The test bench opens up possibilities that the partners in the working group would be unlikely to have on their own. And this is also part of the success story – that we can offer this continuity and keep institutes involved in the long term. We have created something that we can develop further. This is a promise for the future.

Is a test rig still relevant in an age of highly precise simulations?

Schleer: The possibilities offered by simulation are certainly much greater than they were 10 or 20 years ago. Today, you can get a lot of computing power for relatively little outlay. However, because you can simulate everything, you don't know how to assess the results. Simulating 50 geometries and then selecting and verifying the two best ones in experiments is more sensible than what used to be done in the past, when five geometries would be designed based on a gut feeling and tested. The number of simulations will continue to increase, but experiments will remain highly important.

What has been achieved with the test rig up to now?

Schleer: First of all, the installation and commissioning were especially important. Once this had been done, the research focussed on designing the centrifugal compressors using numerical processes and using measuring technology to verify that the design goal had been achieved. The result of this was the transonic centrifugal compressor with design 603, which was the 603rd compressor wheel geometry that was calculated during the numerical optimisation process. Over the last two years we have been using numerical design methods to develop and enhance the industrial compressor stage. The self-funded project is now complete, and we can get involved in projects funded by the AiF [German Federation of Industrial Research Associations].

Who is involved in the Centrifugal Compressor Research expert group?

Bösel: 85 experts from more than 30 companies and four research institutions are collaborating here. Some of them are more involved than others, but the discussions are always very lively and diverse. This is certainly also a key element of the work at FVV – we always have to balance our interests, even though companies of all sizes are involved – from small and medium-sized enterprises to Siemens and MAN. It is this breadth that makes it all so exciting.

What is the specific benefit for the members?

Schleer: Most expert group members cannot generate these results themselves. Thanks to Industrial Collective Research, the companies can take these results and use them to boost their own competitiveness.

Bösel: The platform itself, the pre-competitive exchange between different companies, makes Industrial Collective Research unique – almost worldwide. I don't know of another system with a similar level of intensity and continuity. //

Centrifugal Compressor Research

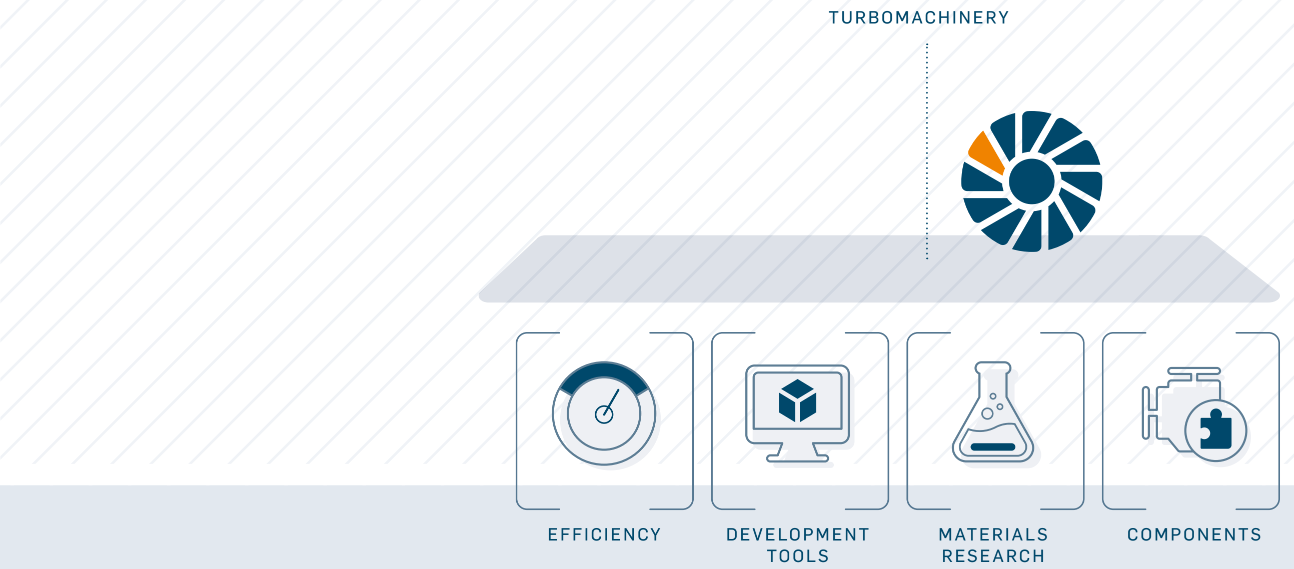
PROJECT LIST

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Completed Projects	
83, 115	Centrifugal Compressor // FVV-EM // 01-01-1969 to 31-12-1972	**E. Schnell,** Klöckner-Humboldt-Deutz
148, 149	Centrifugal Compressor I // FVV-EM // 01-01-1973 to 31-12-1974	**E. Schnell,** Klöckner-Humboldt-Deutz
182	Centrifugal Compressor III // FVV-EM // 01-01-1975 to 31-12-976	**E. Schnell,** Klöckner-Humboldt-Deutz **G. Eisenlohr,** KHD Luftfahrttechnik
233	Centrifugal Compressor - Blade Vibrations // FVV-EM // 01-01-1979 to 31-12-1981	**Dr. B. Jäger,** MTU
269	Centrifugal Compressor - Interaction I // FVV-EM // 01-01-1981 to 30-06-1983	**G. Eisenlohr,** KHD Luftfahrttechnik
306	Centrifugal Compressor - Interaction II // FVV-EM // 01-07-1983 to 31-12-1984	**G. Eisenlohr,** KHD Luftfahrttechnik
396	Centrifugal Compressor - Fatigue Strength // BMWi/AiF // 01-01-1987 to 31-12-1989	**Dr. B. Jäger,** MTU
397, 469	Guide Vane Control I // BMWi/AiF // 01-01-1990 to 31-12-1991	**Dr. R. Keiper,** KK&K
493	Centrifugal Compressor with high Absorption Capacity I // BMWi/AiF // 01-01-1991 to 31-12-1993	**G. Eisenlohr,** KHD Luftfahrttechnik
604	Centrifugal Compressor with high Absorption Capacity II // BMWi/AiF // 01-01-1994 to 31-12-1995	**G. Eisenlohr,** KHD Luftfahrttechnik
606	Spiral Flows // FVV-EM // 01-06-1994 to 31-05-1997	**Dr. R. Keiper,** KK&K
670	Transonic Centrifugal Compressor I // BMWi/AiF // 01-01-1997 to 31-12-1998	**G. Eisenlohr,** Rolls-Royce
729	Transonic Centrifugal Compressor II // BMWi/AiF // 01-04-1999 to 30-04-2020	**G. Eisenlohr,** Rolls-Royce
705	Guide Wheel Optimisation // FVV-EM // 01-04-1998 to 31-10-2000	**W. Röppischer,** Siemens
763	Spiral Flows II // BMWi/AiF // 01-06-2000 to 30-04-2003	**Dr. R. Keiper,** KK&K
781	Sound Generation in Centrifugal Compressors // BMWi/AiF // 01-09-2001 to 29-02-2004	**Dr. A. Rippl,** MAN B & W Diesel
798	Homogeneous Rotor/Stator Flow // BMWi/AiF // 01-08-2002 to 30-04-2005	**Dr. K.-H. Rohne,** ABB
823	Centrifugal Compressor Map // FVV-EM // 01-04-2004 to 31-01-2005	**Dr. R. Keiper,** KK&K
845	Dynamic Surge Line // BMWi/AiF // 01-07-2004 to 30-06-2006	**Dr. J. Wolkerstorfer,** AVL List
846	Optimisation of Inlet Guide Vanes for Centrifugal Compressors II // BMWi/AiF // 01-07-2004 to 30-06-2006	**Dr. R. Keiper,** KK&K
861	Radial Compressor Noise II (A) // FVV-EM // 01-02-2005 to 31-01-2006	**Dr. A. Rippl,** MAN B & W Diesel
894	Compact Diffuser // FVV-EM // 01-09-2006 to 28-02-2009	**Dr. K.-H. Rohne,** ABB
901	Radial Compressor Noise II (B) // BMWi/AiF // 01-03-2006 to 28-02-2007	**Dr. A. Rippl,** MAN B & W Diesel
949	Radial Compressor Noise III // FVV-EM // 01-01-2008 to 31-03-2009	**Dr. A. Rippl,** MAN B & W Diesel

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
2300	Advanced Centrifugal Compressor Test Rig // FVV-EM // 15-09-2011 - 31-12-2015	**Dr. K.-H. Rohne,** ABB
1116	Validation NUMECA-C // FVV-EM // 01-10-2012 to 31-12-2017	**Dr. T. Hildebrandt,** NUMECA
1196	Flexible Radial Compressor // FVV-EM, BMWi/AiF // 01-06-2015 to 31-05-2018	**Dr. M. Schleer,** Howden Turbo
1227	Acoustic Emission into Discharge Pipes // DFG, FVV-EM // 01-11-2015 to 31-10-2018	**Dr. R. Büssow,** Industrial Analytics Berlin
1279	Design and Implementation of the FVV Industrial Compressor // FVV-EM // 01-07-2017 to 30-06-2021	**Dr. M. Schleer,** Howden Turbo
1337	Circumferentially Inhomogeneous Centrifugal Compressor Flow // BMWi/AiF // 01-12-2018 to 31-05-2021	**Dr. T. Hildebrandt,** NUMECA

Expert Group Centrifugal Compressors

RESEARCH PRIORITIES



Experimentation is still essential

Researchers from RWTH Aachen University have been running FVV's centrifugal compressor test rig for five years. Prof. Peter Jeschke has accompanied its installation and commissioning from the very beginning – experiencing small setbacks and great successes.

Dozens of cables for the connected sensors dangle from the low, soundproofed ceiling. Cold neon light illuminates a two-megawatt electric motor with flange-mounted planetary gear train on the left, with a several-metre-long inlet pipe and a large silencer on the right. The heart of the installation sits between them: the radial compressor stage, in which an impeller rotates at a speed of more than 20,000 revolutions per minute. Hoses as thick as a person's arm supply the machine with cooling and lubricating oil.

All of this is impressive and expensive – but are such test benches even still needed today, in an age when turbomachines are developed using ever more powerful computers and simulation results are extremely accurate? »Yes – after all, numbers are only one side of the coin when it comes to acquiring new knowledge. Conducting experiments is the only way to calibrate, trim and verify your calculations,« explains Professor Peter Jeschke, Head of the Institute of Jet Propulsion and Turbomachinery (IST) at RWTH Aachen University. Without anything to refer to, the numbers would deliver incorrect results, which is why test benches will be justified for decades yet despite ever better simulation results.

There are very few research locations in Europe where experiments are conducted using radial compressor test benches. One of these is the German Aerospace Center (DLR) in Cologne. In 2011, the decision was taken to build another test rig at RWTH Aachen University, which has been used to continue with FVV research projects ever since. Years of development and set-up work followed, with experts from FVV member companies in the Turbomachinery planning group working together with RWTH Aachen University to design and manufacture the required parts and install and calibrate the measuring technology – classic engineering work. As a result of the extreme level of noise produced by the test bench during operation, a sound-insulated room with 30-centimetre-thick reinforced concrete walls was built specifically for this purpose in the IST machinery hall.

Project data

→ »Advanced Centrifugal Compressor Test Rig [2300]: Construction and validation of a centrifugal compressor test rig at IST, RWTH Aachen University«

→ **PROJECT FUNDING**
€ 465.000 // FVV

→ **PROJECT COORDINATION**
Dr. Karl-Heinz Rohne, ABB Turbo Systems

→ **RTD PERFORMER**
Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

There were pragmatic reasons for the size of the test bench, explains Jeschke: »The spiral housing is from the portfolio of ABB Turbo Systems, so we were able to buy a finished product. In addition, an impeller diameter of around 400 millimetres is regarded as the industry standard and ABB and MAN both work with it.« The biggest advantage, however, is that the researchers have enough space to install the required measuring technology. Smaller test benches are limited in this respect, while in larger rigs, the costs rise drastically alongside the diameter. Only a few test benches with similar performance and measuring equipment exist worldwide. Up to 100 pressure and temperature sensors are used, depending on the project.

Five years and three million euros later, the FVV test bench was ready for use. The test runs were completed in April 2016. In the first research project, the partial load behaviour of radial compressors was to be examined for flexible power plant operation.
On the day of the official commissioning, the test bench sustained its only significant damage to date: »At that time, we still had little experience with the test bench and accelerated to maximum speed much faster following the symbolic start-up than we had done in the previous tests,« remembers Jeschke. This caused the compressor components to heat up and expand at different speeds – as a result, the impeller ran into the spiral housing at full speed and was shortened by several tenths of a millimetre. »Of course, this was annoying, but we only noticed the damage following disassembly,« says Jeschke. Since then, no further technical problems have occurred. However, another ever-present aspect remains: the amount of time needed for the individual research projects is continuously underestimated.

For instance, it can take a year to adapt new measuring points instead of the planned three months; in addition, there are inspection phases during which the test bench is not operated. It took around a year and a half to modify it in line with the current industrial compressor configuration. Training the staff to use the complicated hardware also takes time.

Nearly all of the research assistants and doctoral candidates have studied mechanical engineering, with a focus on the areas of turbomachinery, aerospace or energy technology. Small teams comprising between three and five members of staff support the research projects in a rolling system: most of these teams started at different times, with their older colleagues teaching them how to handle the complex technology. There are occasional capacity bottlenecks, as the test bench is operated by three permanent employees and two of them have to be on site in order to run it.

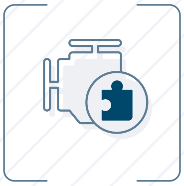
»The topic of acoustics is growing in importance, but it is much more difficult to measure than aerodynamics. On the other hand, you gain more knowledge.«

After around ten days of operation, the impeller is removed and checked; the researchers take this opportunity to fit new sensors or position them at different measuring points. At around €1,000 each, the pressure sensors used for acoustic measurements are not cheap, which is why only around 20 of these sensors are fitted on the test bench. Among others, they are needed for the FVV project *Acoustic Emission into Discharge Pipes II*, in which a previously developed measuring procedure is to be applied until mid-2022. »The topic of acoustics is growing in importance, but it is much more difficult to measure than aerodynamics. On the other hand, you gain more knowledge,« explains Jeschke. The test bench offers ideal conditions for acoustic measurements, as it is designed very closely to the geometry of real industrial compressors. Since its commissioning, the rule of thumb is that it should not be operated for more than one day a week. And for a good reason: »We have to evaluate the data correctly, and that takes time. We must recognise any interference or errors; inaccurate calibration prior to testing can also generate unusable measurement data,« says Jeschke. Slow is precise, and precise is fast.

Many research projects ultimately result in actual products or applications. One of these is the completely numerically designed and optimised impeller 603. »The method of using numerics to optimise components in a completely automated manner is a real success story for collective research. Especially as the method works for all geometries,« says Jeschke. Tests are currently being performed on flow stabilities in an industrial compressor stage with variable inlet guide wheel, in order to determine how these limit the operating range. And, because every research project brings up lots of new questions, the FVV centrifugal compressor test rig will be in operation for plenty of years yet and deliver valuable research findings. //

Research Priorities

DEVELOPMENT TOOLS



COMPONENTS

Stability through variability

At FVV's centrifugal compressor test rig at the Institute of Jet Propulsion and Turbomachinery (IST) at RWTH Aachen University, one of the most powerful research units of its kind in Europe, a new, industry-oriented radial compressor stage with variable inlet guide wheel, has been designed and manufactured. This is used to investigate unstable flows in the partial load range, among other things.

Centrifugal compressors work in the background – yet a modern society simply would not be possible without them: in the transport sector, they are used as turbochargers to boost efficiency, whether in small car engines or in the large diesel engines employed in ships, while in aeroplanes they can be used to produce energy as auxiliary engines. Meanwhile, radial compressors are used on a much greater scale in industry. »In contrast to turbochargers or aircraft engines, industrial compressors are primarily used to convey process gases in industrial plants, such as those in the chemical industry or in metallurgy,« reports Dr Matthias Schleer, head of the Radial Compressor Research expert group at FVV, who adds that increasing demand for the production of renewable fuels is expected over the coming years. The method of functioning – using a rotating impeller to increase the pressure ratio of a fluid – is identical for all centrifugal compressors, however.

In a self-funded project and on behalf of FVV, an industrial radial compressor stage was numerically designed and built at the Institute of Jet Propulsion and Turbomachinery (IST) at RWTH Aachen University from mid-2017 onwards. While the SRV4 impeller designed in a predecessor project and its successor, the 603, have a similar geometry, the industrial compressor wheel differs significantly: both the number of vanes and the geometry are designed for the special requirements of industrial applications. During the conversion, the instrumentation of the test bench was modified and supplemented and the test bench was adapted to the new geometry in order to reveal flow instabilities. A spiral housing was then fitted in the next stage of the conversion. »Technically, everything worked well, although this was expected. The IST has now gathered a lot of experience with the test bench; setting it up required a great deal of technical expertise,« reports Schleer. The working group head believes that the project objective has been fulfilled: »We have laid the technical foundation, converted the test bench, fitted it with measuring equipment and realised a geometry that is typical of an industrial compressor.«

Now that the conversion is complete, the stage has been set for the Industrial Collective Research project *Radial Compressor with Wide Operating Range*[1]. After all, when radial compressors are optimised, the focus is rarely on achieving a higher pressure or volumetric flow: »Depending on the application, the customer needs the broadest possible operating range. The compressor then runs in the partial load range with half the nominal volume flow, yet the pressure ratio is the same,« explains Matthias

1 The project is funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) on the basis of a resolution of the German Bundestag (20494 N).

Schleer, adding: »However, flow instabilities at low mass flows are problematic, as they can cause severe damage to the impeller or even destroy the vane completely.« Furthermore, the throughput of compressors is limited by the choke line at high mass flows. The operating range of compressors is between these two limits.

Project data

→ »Design and Implementation of the FVV Industrial Compressor [1279]: With a variable inlet guide vane for the investigation of flow instabilities that limit the usable map width«

→ **PROJECT FUNDING**
€ 179.990 // FVV

→ »Radial Compressor with Wide Operating Range [1354]: Study and modeling of a centrifugal compressor with the aim to develop methods for predicting instability and map width, thereby enabling a design of an improved industrial compressor with wide map«

→ **PROJECT FUNDING**
€ 249.760 // BMWi/AiF

→ »Centrifugal Compressor in Flexible Operation [1443]: Aerodynamic and acoustic investigations of the interaction between impeller, diffuser and volute casing at operating points remote from the design on a representative centrifugal compressor«

→ **PROJECT FUNDING**
€ 560.000 // BMWi/AiF | FVV

→ **PROJECT COORDINATION**
Dr. Matthias Schleer, Howden Turbo

→ **RTD PERFORMER**
Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

One of the key elements of the industrial compressor is an adjustment device positioned in the flow channel immediately upstream of the impeller. »This variable inlet guide wheel can change the angle of attack and thus apply a targeted pre-swirl to the flow, which then hits the impeller together with the swirl,« explains Schleer. This allows the flow conditions at the inlet to be regulated and cover a broad operating range without stalling the flow. In the research project, the flow instabilities that still limit this range are being investigated; this comprises selecting suitable forecasting models, conducting experiments on the centrifugal compressor test rig, performing numerical flow simulations and comparing the data from the numerical simulations and the experiments.

All members of the FVV Radial Compressor Research expert group are benefiting from the construction of the industrial compressor and the results it generates: whether manufacturers that produce radial compressors and impellers for their customers, or providers of calculation software that are reliant on the latest research results. They can use the gathered data to calibrate and verify their development tools and calculation models – and thus prove to their customers that the product or consultation service is at the cutting edge. As Schleer comments: »The value of a radial compressor or impeller is not so much in its manufacturing as in its design, its calculation and in the verification that it is safe.«

Several teams of researchers benefit from the new test bench configuration at the IST. Alongside *Radial Compressor with Wide Operating Range*, investigations are also being performed in the area of acoustics. In this connection, a newly developed measuring procedure is being used to determine the sound power transmitted into discharge pipes during experiments [→ page 20]. Another project is also about to begin: in the follow-up project *Centrifugal Compressor in Flexible Operation*, the impeller and inlet guide wheel will be identical to the current configuration; however, the researchers will also fit a new vaned diffuser between the impeller and the measuring point[2]. By the beginning of 2024, aerodynamic and acoustic investigations will examine how the impeller, diffuser and spiral housing interact in operating points that are still within the intended operating range, yet far from the optimal operating point. The instrumentation required for the acoustic measurements has already been fitted on the test bench.

Because the vanes of the impellers are subjected to extremely high loads at the top speed, head of the expert group, Schleer, has already defined further need for research: the effects of stability limits on vane vibrations and thus on the mechanical design could be a research project for the future. //

2 The project is funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) on the basis of a resolution of the German Bundestag (03EE5067)

Sounds that break steel

Researchers from TU Berlin and RWTH Aachen University have developed two sound measurement techniques that could replace the currently applicable DIN standard for acoustic measurements of centrifugal compressors. Initial investigations on the centrifugal compressor test rig at RWTH Aachen University show a good correlation between the simulation results of both partners and the measured results from the test rig.

»There are high-frequency oscillations that can destroy all components such as pipelines, the compensator or the silencers. They break steel as if it were an icicle,« explains Dr Irhad Buljina from MAN Energy Solutions, underlining the relevance of acoustics. After all, the possible effects are often underestimated, and industrial companies have problems implementing the required sound protection measures. In steel works with large geared compressors, the entire hall sometimes trembles and vibrates. You can even feel your jaw moving when you are standing next to the machines, reports Buljina. He is responsible for the *Acoustic Emission into Discharge Pipes II* research project, which is currently in progress at the Institute of Jet Propulsion and Turbomachinery (IST) at RWTH Aachen University and the Institute of Flow Mechanics and Technical Acoustics (ISTA) at TU Berlin.

The primary source of noise on a radial compressor is the impeller, which at certain frequencies creates sounds that dominate the radiated sound field. These stimulate acoustic sound field structures, known as modes, which in turn transport sound energy through the connected pipelines. The modes cause acoustic pressure fluctuations, which can trigger structural vibrations in the exterior walls of pipelines at certain frequencies. This is particularly disruptive when the excitation frequency matches the resonance frequencies of other pipelines – such an air-structure-air coupling enables the emission of disruptive noise in the vicinity of the compressor. In order to dimension protective measures such as acoustic hoods or pipe insulation correctly, the internal sound power of the compressor must be known – and this differs from one case to the next. »At MAN, we rarely build the same machine twice – everything is matched to customer needs. Therefore, we have to redesign the sound protection measures again and again,« comments Buljina, explaining why further research is needed. Professor Lars Enghardt from TU Berlin adds: »The rule is as follows: if you prevent sound emissions through a low-noise design, you don't have to invest in expensive sound insulation or provide more space for larger silencers at a later stage.«

»There are high-frequency oscillations that can destroy all components such as pipelines, the compensator or the silencers. They break steel as if it were an icicle.«

In order to comply with occupational safety regulations, the sound radiation on the pressure side of radial compressors must therefore be quantified precisely. However, the standard measuring procedure currently used is too imprecise and too expensive, as the time and effort required to install heat-resistant sensors on the pressure side is enormous. In the form of *Acoustic Emission into Discharge Pipes*, one of the first research projects was therefore conducted on the centrifugal compressor test rig from 2015 onwards with the aim of developing a new measuring procedure.

Researchers from RWTH Aachen University performed CFD simulations for four operating points on a characteristic speed curve in order to measure the acoustic excitation and sound propagation up to the connected discharge pipe. »The complex geometry on the pressure side of the compressor meant that a full-annulus simulation was necessary. The calculation matrix also had to be finely resolved in order to prevent numerical dissipation effects at the relevant high frequencies,« explains Marius Geilich, Research Assistant at the IST at RWTH Aachen University. The resulting calculation matrix with around 170 million nodes and the high time resolution of up to 2,000 time steps per impeller revolution could only be managed by high-performance computers. To this end, the researchers had access to Europe's fastest computer at the research centre in Jülich. Colleagues at TU Berlin then recorded the propagation of sound through the connected discharge pipe using efficient CAA simulations. The new findings were used to develop two alternative measuring procedures, which allow the sound power to be predicted reliably, precisely and affordably.

In the follow-up project, *Acoustic Emission into Discharge Pipes II*, the level of maturity for application in an industrial environment is now being verified through experiments. This is posing a number of challenges for the researchers. After all, positioning and calibrating the sensors is tricky: if numerous sensors are distributed across the circumference of the discharge pipe, not all of them will measure the same result; however, the measured data differs if they are positioned in the longitudinal direction, too, as a result of interference effects due to the spreading sound modes. A total of 16 piezoelectric sensors were used for the acoustic measurements, as these have the necessary degree of sensitivity. The transfer behaviour of the sensors at high temperatures and pressures had previously been verified at TU Berlin's hot acoustic test rig. This ensured that all sensors have the same transfer properties in terms of the magnitude and phase of the sound signals.

Project data

→ »Acoustic Emission into Discharge Pipes I [1227]: Development and validation of a measurement method for determination of the sound power radiated by a centrifugal compressor into the discharge pipe«

→ **PROJECT FUNDING**
€ 515.000 // DFG | FVV

→ **PROJECT COORDINATION**
Dr. Richard Büssow, Industrial Analytics

→ »Acoustic Emission into Discharge Pipes II [1383]: Experimental application of a newly developed measurement technique to determine the in-duct sound power level emitted by a centrifugal compressor into the discharge pipe«

→ **PROJECT FUNDING**
€ 491.950 // DFG | FVV

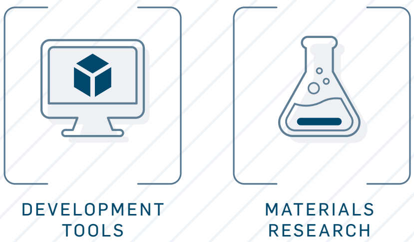
→ **PROJECT COORDINATION**
Dr. Irhad Buljina, MAN Energy Solutions

→ **RTD PERFORMERS**
Institute of Flow Mechanics and Technical Acoustics (ISTA) TU Berlin | Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

The measuring technology was implemented at the test rig at RWTH Aachen University. Experiments were conducted in order to determine the sound power for three characteristic speed curves and a multitude of operating points. Although the research project will run until mid-2022, success already appears to be on the horizon: »We presented interim results at a meeting of the working group and everyone was surprised at how well the results from the simulation matched the measurements on the test rig,« says Irhad Buljina.

IST head Professor Peter Jeschke is convinced: »We expect that the procedure will replace the currently applicable DIN standard for this type of radial compressor, as we can now measure noise much more precisely. This is a very good result that can also be put to use by industry.« After all, he continues, a lack of such knowledge is preventing the engineers from developing quieter machines. The research results will allow conclusions to be drawn as to where optimisation will be possible in the future. For example, the distance between rotating and stationary parts can be altered, while the number of vanes and geometry can also be adapted with only minor losses in efficiency. Both manufacturers of centrifugal compressors and companies that develop and produce sound protection products should benefit from the research results. The researchers in Aachen and Berlin are now expanding the measuring procedure's scope of application to include industrial compressors with vaned diffusers. //

Research Priorities



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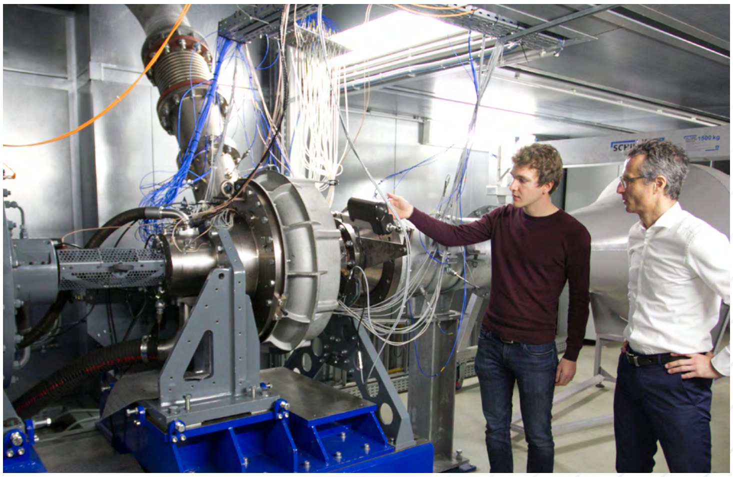

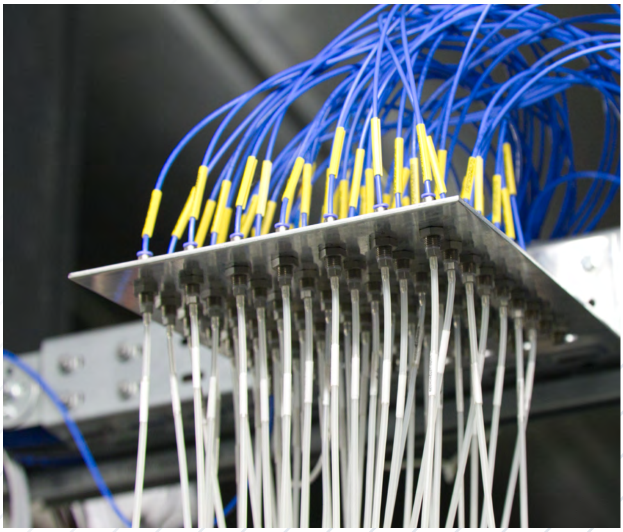

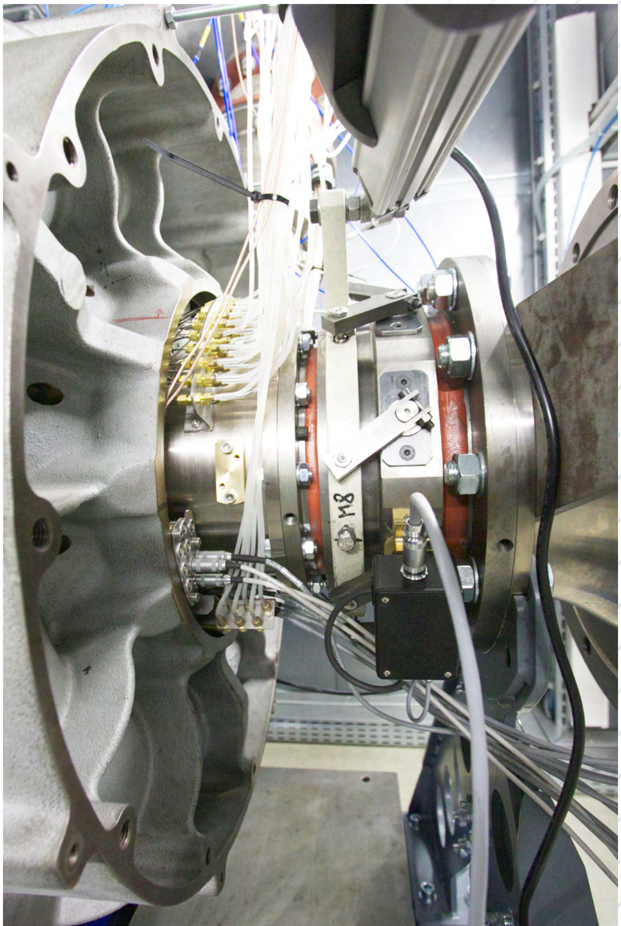

When the new centrifugal compressor test rig at RWTH Aachen University was commissioned in 2016, it enabled scientists to conduct research under real-life conditions. The research spectrum was extended to include experimental projects such as:

- »Design and Implementation of the FVV Industrial Compressor [1279]«
- »Circumferentially Inhomogeneous Centrifugal Compressor Flow [1337]«
- »Radial Compressor with Wide Operating Range [1354]«
- »Acoustic Emission into Discharge Pipes II [1383]«
- » Centrifugal Compressor in Flexible Operation [1443]«

REPORT ANNUAL MAGAZINE

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Turbocharging Progress

Some machines are hidden away so well that they are barely noticed by the public – despite playing a decisive role in the progress of an industrialized society. This is the fate of the centrifugal compressor. However, Europe is the global technological leader in industrial centrifugal compressors. And leading positions also have to be defended. Industrial Collective Research is a proven instrument that lays the groundwork for this. The Centrifugal Compressor Research expert group founded within FVV more than 50 years ago successfully coordinates this collective research – laying an important foundation for an industrial country that is switching its energy supply to renewable sources.

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