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Hydrogen engines and the new Comprex™ pressure wave supercharger concept

Wasserstoff Motoren und das neue Comprex™ Druckwellenlader Konzept

Abstract

Hydrogen Engines are in focus to meet the future legislations concerning our environment. Prof. Eichlseder (Univ. Graz) published new measurements last year (2020) which showed the need for a sequential turbo charging concept to get an optimum out of the used hydrogen engine. The new Pressure Wave Supercharger (PWS) Comprex™ fulfils these needs perfectly due to a sequential charging system by design and even more, like an included engine break and power turbine. Seems like it would have been specially developed for this application. See also [16].
The new concept will be shown in this paper and why it fits perfect to hydrogen Engines. Also, the new possibilities regarding the exhaust gas treatment to reach ultra-low emissions and the response and efficiency of the Comprex™ System will be discussed.

Kurzfassung

Wasserstoffmotoren sind im Fokus, um die zukünftigen Umweltgesetze erfüllen zu können. Prof. Eichlseder (Univ. Graz) veröffentlichte im vergangenen Jahr (2020) neue Messungen, welche die Notwendigkeit eines sequenziellen Turboladerkonzeptes aufzeigten, um ein Optimum aus dem verwendeten Wasserstoffmotor herauszubekommen. Der neue Druckwellenlader (DWL) Comprex™ erfüllt diese Anforderungen durch ein sequentielles Aufladesystem aufgrund seiner Konstruktion und noch einiges mehr, wie eine eingebaute Motorbremse- und Leistungsturbine. Es scheint, als ob der DWL speziell für diese Anwendung entwickelt worden wäre. Siehe auch [16].
Das neue DWL Konzept wird in dieser Veröffentlichung vorgestellt und warum es perfekt zu Wasserstoffmotoren passt. Auch die neuen Möglichkeiten in Bezug auf die Abgasbehandlung, um extrem niedrige Emissionen zu erreichen und das Ansprech-verhalten mitsamt der Effizienz des Comprex™-Systems werden diskutiert.

Introduction

The Pressure Wave Supercharger (PWS) is one possibility beside a turbocharger and a compressor to supercharge a combustion engine. In this report a new concept will be shown that fits well to the requirements of hydrogen engines.
The pressure wave supercharger (PWS) has been used to supercharge diesel engines since the 1940s. At that time, the BBC in Baden Switzerland started producing a PWS, the so-called Comprex ™ (Comprex™ is now a trademark of the Antrova AG sister 3prex AG). PWS applications were first developed in the 1940s as additional stages for locomotive gas turbines by the Brown Boveri Company (BBC). Between 1947 and 1955, the ITE Circuit Breaker & Co in the USA under the leadership of the BBC produced units and successfully tested them on diesel engines [9]. The machine itself is therefore much more recent than the turbocharger, which exists since 115 years [1], now. Mainly, the PWS was successfully used at former GM daughter Opel and mostly by Mazda. There was also a free-running machine [14] under development without a belt drive. The disadvantage of these free running rotors, which are driven only by exhaust gas, is that a special air valve is required for starting and that the rotor speed can never be optimally adjusted. Especially since the rotor must be braked from a certain operating point, because the rotor speed should not become too fast. This point will be exceeded relatively soon at today's level of supercharging with a lot of exhaust gas energy.
With an electric drive, however, this effect can be used to feedback electricity into the battery. Although the concept seems older, it promises great advantages for combustion engines today and it was almost used as an electrically powered version (Hyprex; short for Hybrid Comprex™) in the Mercedes AMG A45 in 2012.

Many investigations have recently been carried out on this PWS. See [2], [4], [10], [11], [12], [13]. Despite the spectacular possibilities and many advantages for the downsizing concept [4], [5], [6], [7], the PWS has so far not been able to assert itself due to cost reasons in the manufacture of the cell rotor and the "old design" problems.

But how is the situation to be assessed by the legislator based on the new boundary conditions for emissions and can a new PWS concept help to overcome the old disadvantages? The problem that all internal combustion engine developers have is the increasing demand on environmental compatibility, which of course also goes hand in hand with high costs for exhaust gas cleaning. Here you could go further with the help of a charger that extends the normal scope to get more benefits for the environment.

However, the general advantages and the principle of operation will be described, followed by an analysis of the hydrogen engine measurements made in Graz. Then the new concept will be shown in comparison to the old one in order to make the improvements clear.

Also, the measurement activities of the prototype will be addressed, which come from the hot gas test bench in order to establish a better practical relevance and to show that a considerable effort is made here.
The problem of the temperature dependent gaps in between the rotor and the casings and the controllability should be much better to handle. This is achieved by a new bearing concept with the aid of a water-cooled exhaust gas housing, a central divided two-part rotor and the ability to turn off one of the two gas-dynamic cycles like a sequential charging system with VTG turbines. The advantages against the old concept and the advantages that such a PWS generally offers in terms of efficiency and emissions are reported.

1. Function of the pressure wave supercharger (PWS)

Advantages:

- Very fast boost pressure response
- High boost pressure already at low engine speed
- Its electric drive is used only for synchronisation of the charger compared to the engine speed and can be used for power recovery as well.
- Live time lubricated bearings, no impact on engine oil no blow by, no thrust bearing needed, very reliable.
- The PWS compensates every operational height! No over speeding necessary like Turbochargers do for high altitudes, very reliable.
- The PWS already absorbs the engine noise. Therefore, only a very simple exhaust system without heavy damper is needed
- Very high compression efficiency, possible at low engine speed
- No surge limits as usual by using a turbo compressor
- Low backpressure allows reduction of fuel consumption
- If needed, the catalytic converter can be arranged between the engine and the PWS which leads to a quick light off and much less emissions.
- High EGR rates are easy to represent.
- Very good suitable for Downsizing means less fuel consumption
- Very low exhaust gas temperatures due to mixing with fresh air
- No kind of costly compressor and turbine maps applicable. Simulation must work with a physically 1-D model.

Disadvanteges:

- Need for small back pressure on the low-pressure part requires larger exhaust system cross sections. The same on the air intake part of the PWS.
- Cold start behaviour of the PWS, more difficult to master in gasoline engines, gas and hydrogen engines. Thanks to the new concept significantly improved.
- Matching is more complicated but can be done now in advance with simulation software such as AVL BOOST or GT Suite.

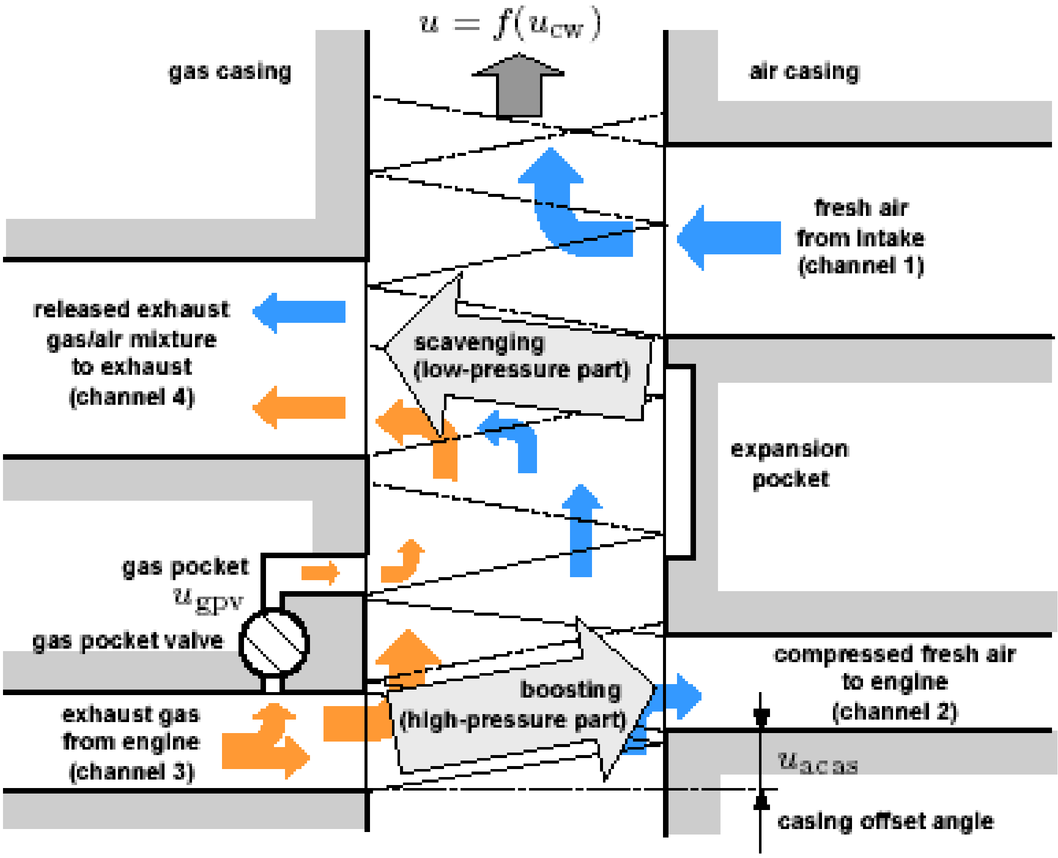

Figure 1.1: Simplified representation of how a PWS works (one cycle)

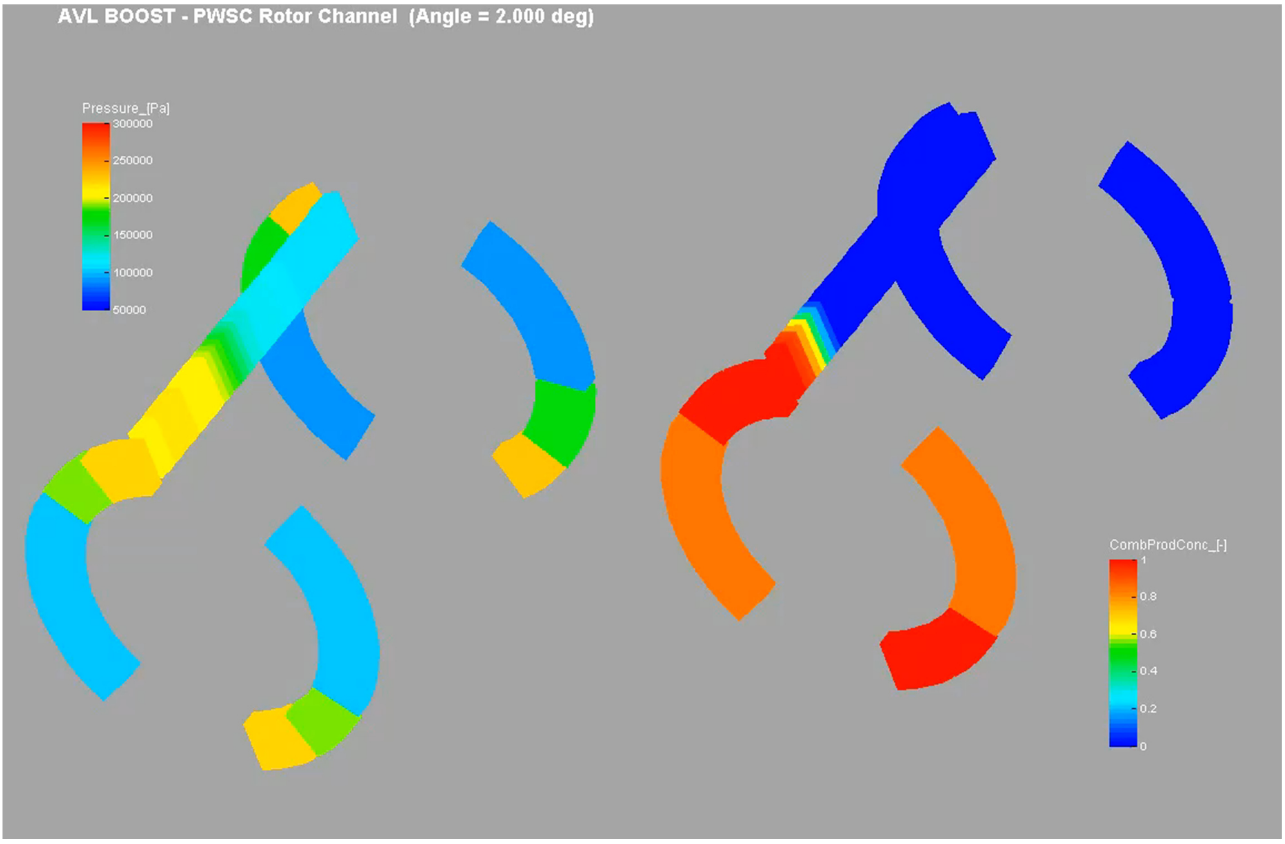

Figure 1.2: Animation of the two working cycles of a PWS from AVL BOOST (one cell)

In pressure wave machines such as pressure wave chargers, pressure exchangers or shaft rotors, the pressure energy is transferred from one medium to another by bringing the two fluids into direct contact for a very short time in long, thin channels, the so-called rotor cells. Pressure wave machines use the physical principle that after two media are brought into contact with different pressure, the pressure equalization takes place faster than any mixing. However, in case of the Comprex™ mixing of exhaust gas and fresh air does not really take place due to a different density.

The pressure wave process can basically be divided into two phases: the high pressure and the low-pressure process (Fig. 1.1). In the high-pressure process, the exhaust gas enthalpy in channel 3 is used to compress the fresh gas flowing into channel 2. Part of the enthalpy of exhaust gas can be passed through the gas pocket valve, which on the one hand reduces the pressure in channel 3 and thus the compression of the gas in channel 2. On the other hand, the pressure in the rotor cells is increased shortly before the start of the low-pressure cycle, which improves the flushing in the low-pressure process. The aim of the low-pressure process is to purge the rotor cells filled with exhaust gas in the direction of duct 4 and to fill them with fresh air from duct 1. Therefore, duct 4 is not only filled with exhaust gases in normal operation, but also always with fresh air, which was compressed in the high-pressure process but did not flow into duct 2. Therefore, the temperatures of the exhaust gas are lower than with the turbo engine because a mixture of hot and cold gases takes place.

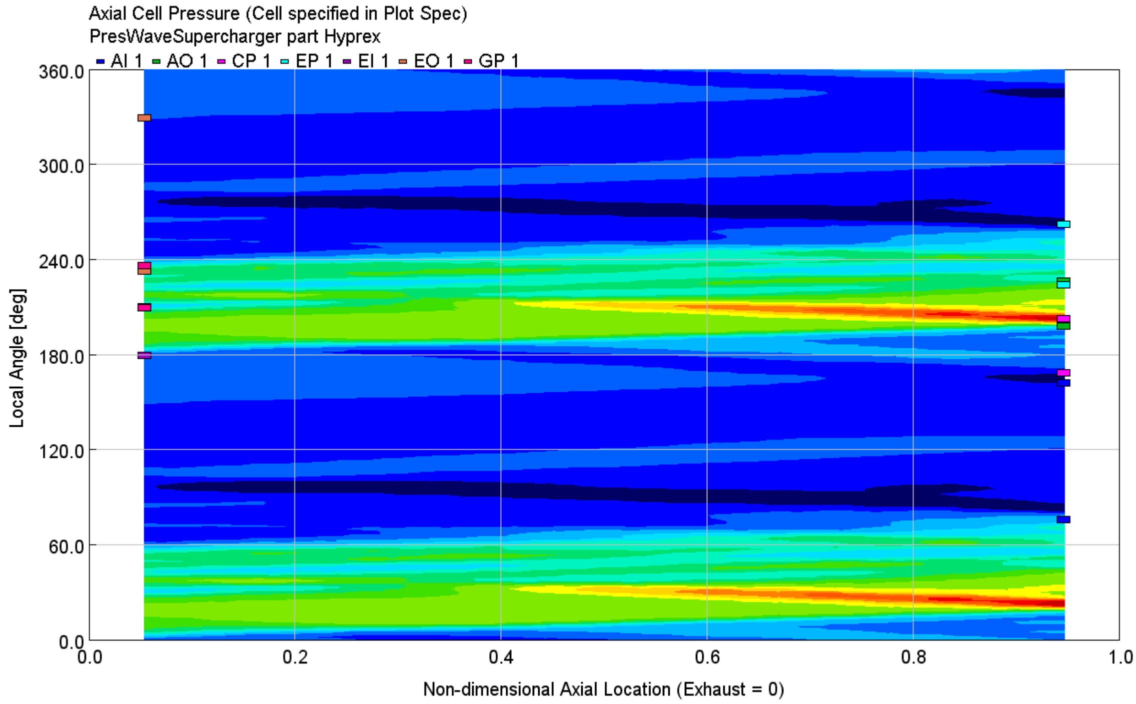

Figure 1.3: Taken from GT Power Simulation, handling two PWS cycles (highest pressure level in red)

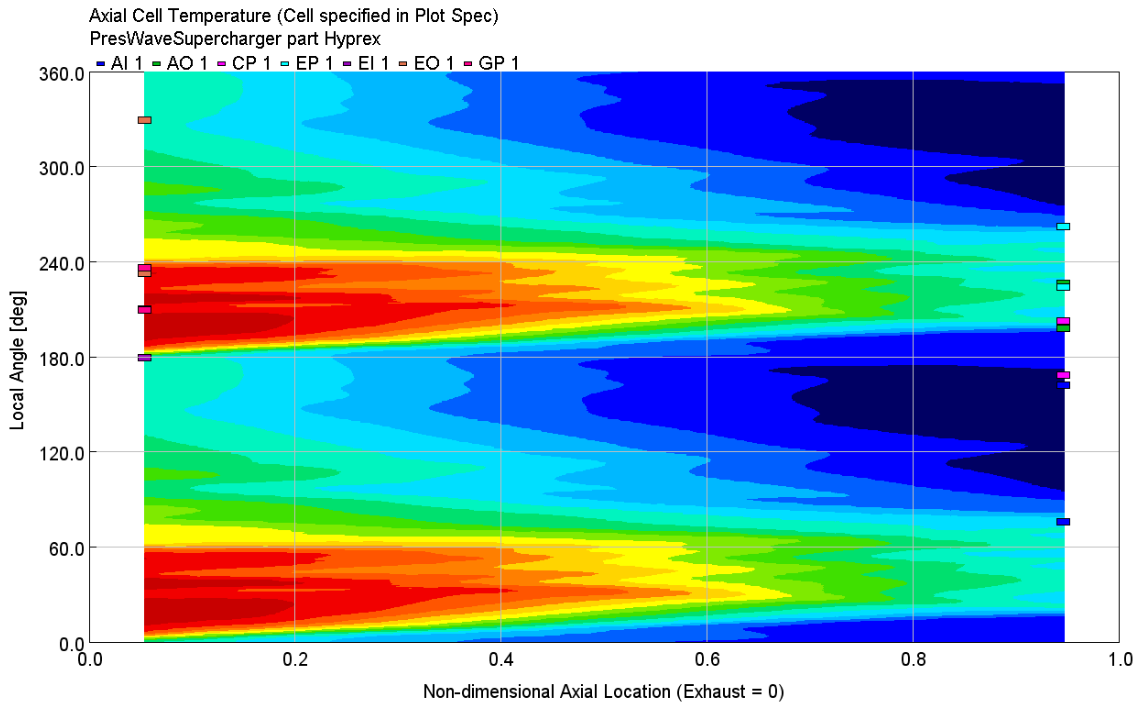

Figure 1.4: Taken from GT Power Simulation, handling two PWS cycles (highest temperature level in red)

The channels connected in the sketch are all open towards the rotor, the width of the channels is not being arbitrary. Seen from a rotor cell, certain closing and opening angles must be observed so that the timing for the gas dynamics is correct, otherwise the PWS will not work. The channels are also subject to certain inflow and outflow angles to get not too large incidences during the transition between the rotor to the housings. They are not directed towards the rotor as straight as shown in Figure 1.1.

Expected Performance of a Comprex™ PWS on a Hydrogen Engine

After showing some basics of a PWS we come to the point why a PWS should fit perfectly to a Hydrogen Engine. First let's have a closer look at a paper of Bosch and the Institute for Combustion Engines and Thermodynamics in Graz created by Dr. Pauer and Prof. Dr. Eichlseder (15). It was shown at the IWM in Vienna in 2020 where the following acknowledgements are very interesting.

Results and Experiences taken from the measurements

For the measurements of Prof. Eichlseder two VTG turbochargers were used to be able to get the engine running with a high efficiency. A small Turbocharger for engine speeds below 3000 rpm and a large Turbocharger for speeds above was mounted. This is caused by the fact that high air fuel ratios lead to low exhaust gas temperatures. This makes it much more difficult to reach high-pressure ratios in hydrogen engines. What are the main findings we can take from this paper?

Prof. Eichlseder first mentioned the point that the turbocharging system must be able to produce high pressure ratios to compensate the displacement effect of the air flow upstream the inlet valve of the engine due to the injected Hydrogen with PFI setup. What does this mean in numbers?

It is a fact that Hydrogen has a larger specific volume as air. Looking at the gas equation p*v=R*T or v=R*T/p where v is the specific volume [m3/kg] and R the gas constant of the used medium [J/kgK] , T the temperature in [K] and p the pressure in [N/m2].
Using a simplification with the same temperature und the same pressure it is only the gas constant that is changing from 287.1 J/kgK for dry air to 4124.2! J/kgK for Hydrogen. The result is a specific volume of Hydrogen that is 14.4 times larger than dry air in this case.

One may think by a first glance, that with a stoichiometric air fuel mass ratio (Lambda) above 2 and a stoichiometric air fuel mix of 34.3, the impact of the mixing with hydrogen is negligible, but the opposite is the case. A simplified calculation using the factor 14.4 shows.

The part of the hydrogen in the volume flow upstream the engine is =1/(2*34.3)*14.4=0.21 or 21% with a Lambda of 2. This effect may increase especially if the engine should run in a stoichiometric mode. This number is in reality even higher and about 29.6% due to different pressures and temperatures of air flow and hydrogen flow.
It is clear that an DI Engine can avoid this effect, but a high-pressure injection is needed to get enough pressure ratio for the demanded injection mass flow against the rising cylinder pressure. In this case up to 170bar! had to be used, because the bores in the excising injectors where to small. By looking at the bmep values it can also be seen that these values for the DI version are much higher. It is clear, that in this case more fresh-air can enter the

cylinder and it looks like there will be an additional in-cylinder-compression by the injected hydrogen.

But in every case PFI or DI, the exhaust gas temperatures stay on a much lower level compared to a petrol or gas engine running with Lambda 1. That's the reason the "sequential" turbocharger setup was used, which is difficult to handle around 1200 rpm of the engine. The small turbocharger has his borders concerning surge line and over speeding, which is indeed not easy to control in transient conditions. This leads to another important point. The response behaviour of such an engine setup under transient conditions!

Prof. Eichlseder mentioned it by the fact, that dynamic H2 engine driving behaviour could or should be improved by using electrified vehicles like Hybrid. But this solution is very expensive.

We learned also from these measurements, that especially at low engine speeds the charging system should be able to deliver more air to the engine to decrease the NOx Emissions as far as possible.

This leads us to the NOx emissions. It was found that a lack of air increases the NOx values immediately. While the NOX values stay at 10 ppm with higher Lambdas around 2.5, a Lambda of 1.8 causes values of more than 1000ppm. These values where found at max bmep at 2000 rpm of the engine in PFI modus. If a catalyst is used, another problem appears concerning its working temperature.

Looking at the temperatures given in this paper, the maximum upstream of the turbine is around 600°C in PFI mode. Together with the high-pressure ratios of the turbocharger this causes quite low temperatures (T4) downstream the turbocharger. Depending on the turbine efficiency we can find the following example.

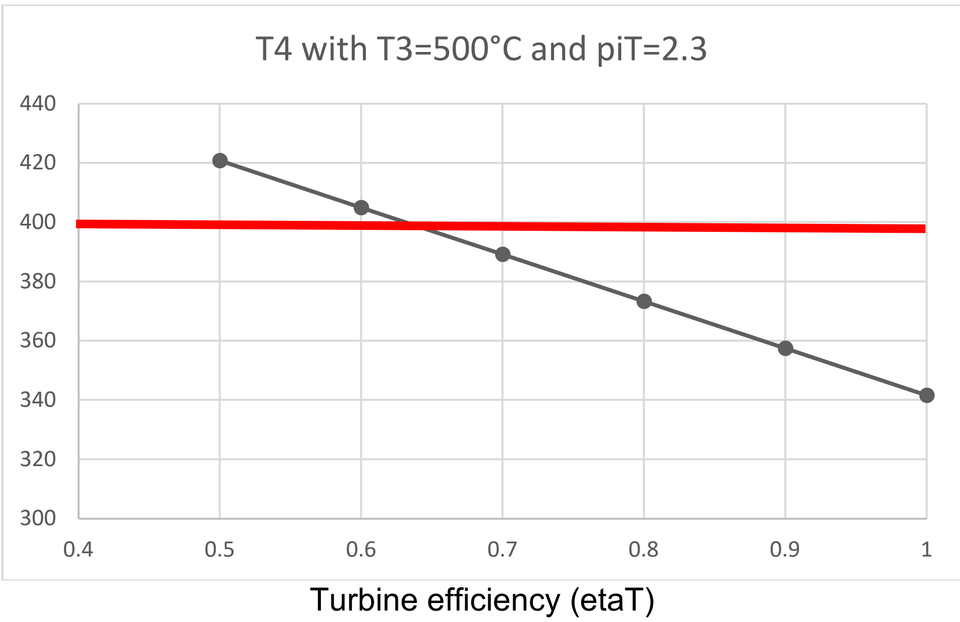

Figure 1.5: Temperature after Turbocharger turbine

The data was also taken from the measurements with PFI setup at bmep=13bar at 2000 rpm there we can see a T3 of 500°C and a manifold pressure of 2.4 which leads to an approximative pressure ratio at turbine of 2.3.

The red line in Fig. 1.5 shows the minimum temperature until a catalyst works usually with 100% performance and it is clear to see that usual turbine efficiencies between 0.6 and 0.7 causing that the catalyst is already running on the “edge”. The isentropic temperature after turbine is shown at etaT =1. It is also known that elderly catalysts need more temperature for a 100% performance. So, it would be good to have a system where the catalyst runs always with higher temperatures.

Another mentioned point by Prof. Eichlseder is that as less as possible oil should get into the burning chamber to avoid uncontrolled combustion and further HC emissions. But how could this Situation be improved?

What is the motivation to use the Comprex™ System

First of all, it sounds quite complicated to run a sequential turbocharging system under these conditions and it would be very interesting to get all this more easily and cheaper of course. If an alternative to such a turbocharging device would also be able to produce much better thermodynamically results, this would be a second reason to have a closer look on it.

Concerning easiness and price the Comprex™ is a very good alternative, due to the fact that all needed functions are integrated in one Device. One Comprex™ can do the same as a turbocharging system with two VTG-Turbochargers by using only two actuators and one e-motor for rotor speed synchronisation.

For example, the number of needed actuators and sensors for the Turbocharger (TC)-system is 2x VTG, 1xWG, 2xAir Flaps and 1 Flap for the engine break modus. Means up to six actuators accompanied by several sensors for pressure and TC speed to achieve the same functional system. The Comprex™ needs only 2 actuators plus the e-motor for the same scope.

Concerning the thermodynamically point of view there are strong reasons why a Comprex™ would fit best to a Hydrogen engine. It was mentioned that problems with overspeed occur. The small TC may easily run into overspeed and get destroyed and the charge air pressure is restricted due to the max speed of the TC. The Comprex™ has no overspeed problem due to the fact, that the charge air pressure is build up only by direct contact of the fresh air and the exhaust gas. A second reason why the Comprex™ is easier to handle in this context is the absence of a surge line as already mentioned in the introduction.

The Comprex™ has a very good response behaviour. An expensive and heavy hybrid drive might be obsolete in most cases.

In this field the Comprex™ is also very useful due to lifetime lubrication of the bearings. There is no connection to any oil circuit needed as it is common using a Turbocharger. Means no influence on combustion in the engine and less HC emissions.

For all engines, modern simulation programs such as GT SUITE or AVL BOOST can be used to integrate pressure wave superchargers into an engine concept. In this case a comparison of simulated and measured data are shown. Due to the fact, that the DI Engine has less problems to reach higher performance the PFI Engine was simulated with a Comprex™. The results are very promising and make a further research interesting.

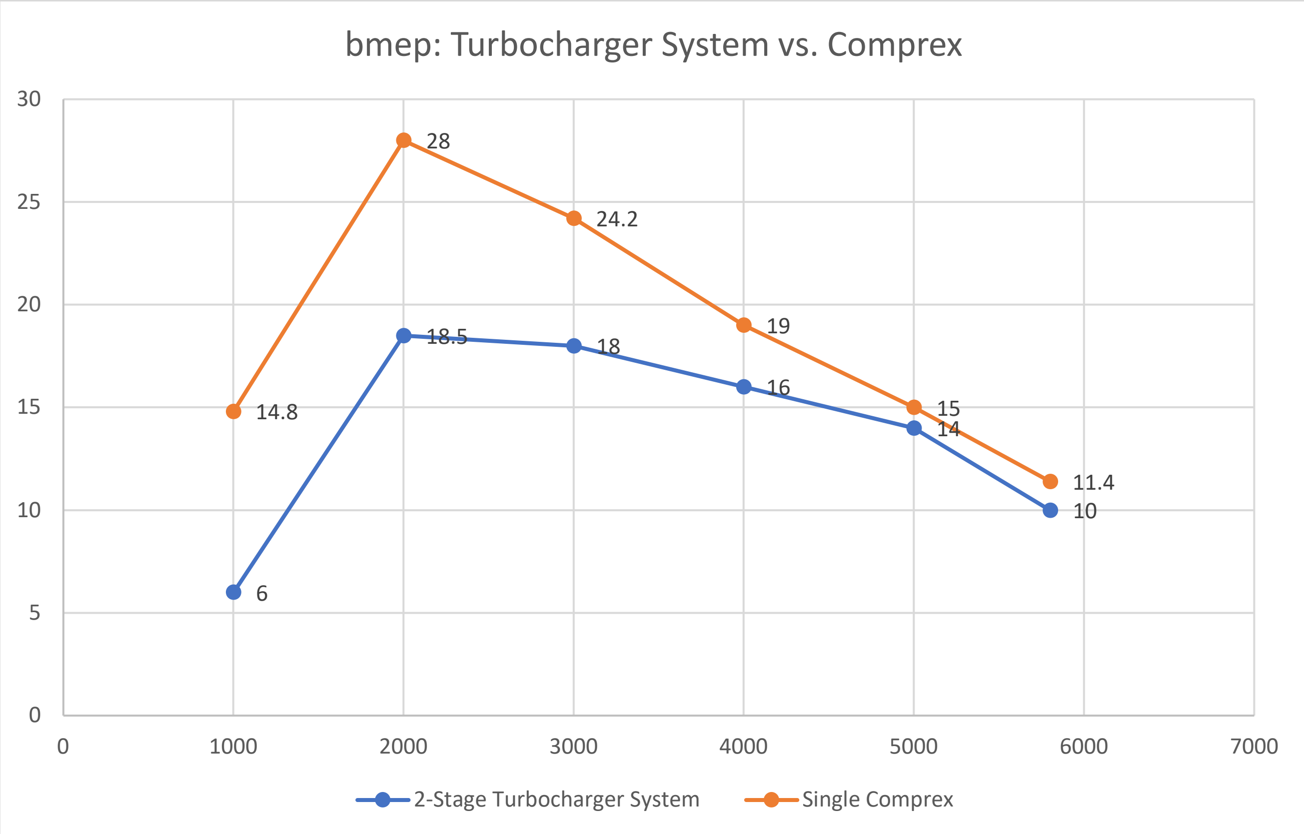

Figure 1.6: Simulated output of a 2 Litre H2 Comprex engine vs. TC measurements

The Figure 1.6 shows the typical behaviour of an PWS engine. A lot of boost pressure at low engine speeds is possible. A maximum bmep of 28bar! which means 223Nm/l is promising for a 2 Litre H2 engine (TC has 148Nm/l). A further point is that the time to torque is very quick, which should create an impressive acceleration that is not comparable to other hydrogen Turbocharged applications. The Comprex™ shown here is designed for a similar maximum engine power to make the improvement at low speeds clearer.

The engine model itself is an "average" engine without any special features. The compression ratio is the same as used for the measurements in Graz and the max cylinder pressures chosen are also comparable.

Concerning exhaust gas temperatures, there was also no need to retard the 50% fuel burned turnover point to reach enough boost pressure with a Comprex™.

How to achieve this Performance with a PWS

In **general:** Table 1.1 the comparison between Turbocharger and Comprex briefly

Known Turbocharger drawbacks vs. Comprex		Comprex	TC
High boost pressure at low rpm of engine		yes	no
Absence of surge line		yes	no
Absence of overspeed problem		yes	no
Absence of turbo lag		yes	no
Absence of oil losses		yes	no
not Backpressue sensitive		no	yes
Quick Catalyst light off		yes	no
any mounting position		yes	no
lower system weight		yes	no
no mufflers saving space		yes	no
multi functional system in one Device		yes	no
low backpressue to engine		yes	no
more reliable		yes	no
1-D physically modeling		yes	no
Common Technology		no	yes
Result		12	2

It is a clear vote for the Comprex™ if this comparison end up with **12:2** for the Comprex™.

In **particular** there is the following to say concerning the new Comprex™ improved concept vs. the old Comprex™.

2. The new Comprex™ Concept

The old concept provided that the rotor bearings where only in the air housing, since no bearing could be accommodated in the gas housing, which was up to 1000°C hot.

Especially with gasoline and gas engines with high exhaust gas temperatures, the rotor needs a huge gap to the exhaust gas housing in the cold state in order to do not touch after it has heated up and the resulting elongation. This is of great disadvantage in the cold start phase since the exhaust gases hardly do any work and flow past the rotor straight towards to the exhaust system.

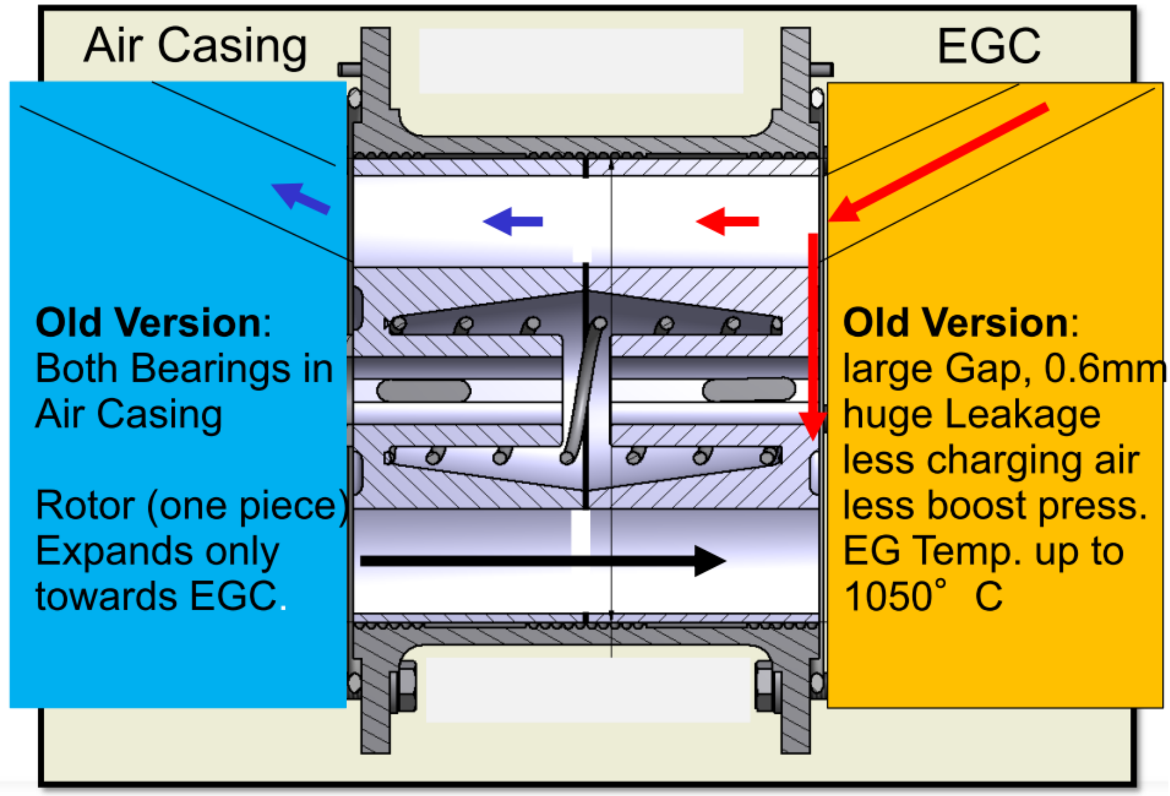

Figure 2.1: Scheme of the old Comprex™ / Hyprex

The new concept, on the other hand, provides a double-walled exhaust gas housing with water cooling in which a bearing can be installed.
The new bearing concept enables the use of a gap in between the rotor and the housings (air and exhaust gas), that leaves always the same distance as small as possible regardless of the rotor temperature.

Of course, this rotor must also be able to grow according to its temperature. For this purpose, the rotor is divided in the middle and has a small gap there, which practically closes in operation, see Figure 2.2.

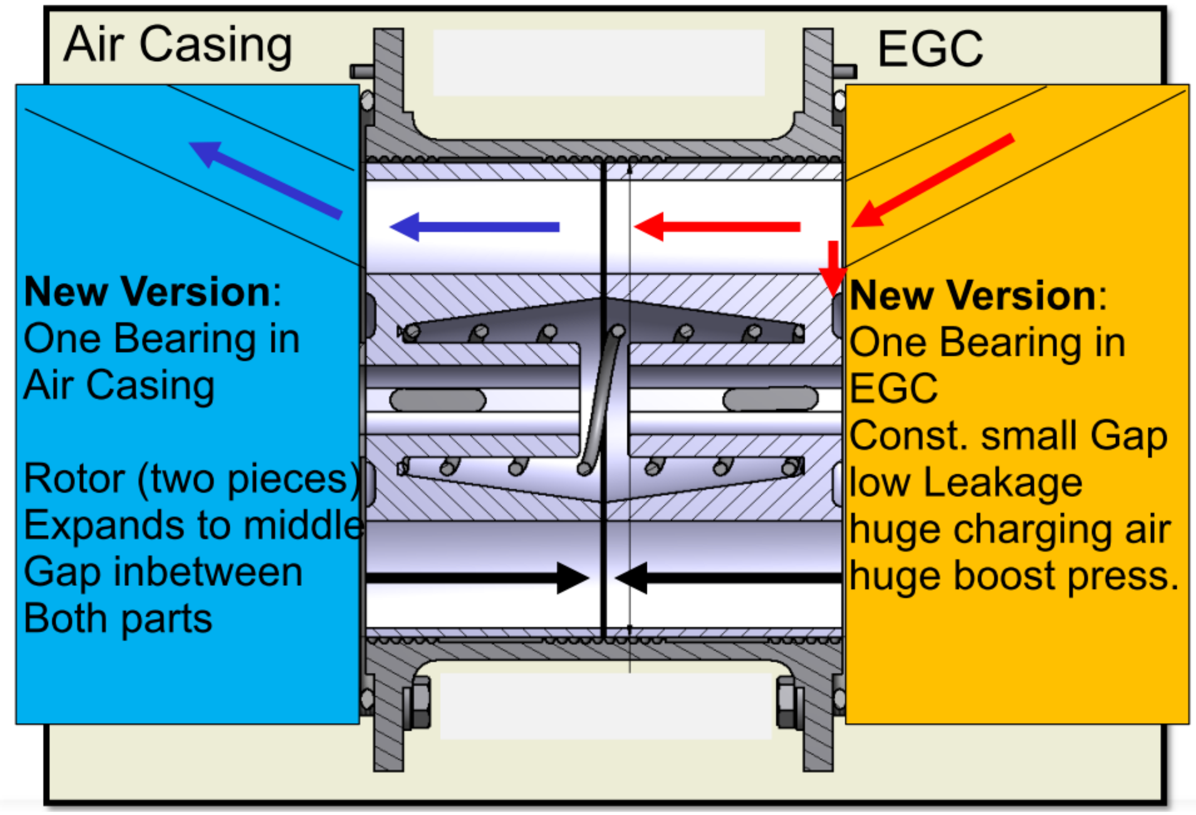

Figure 2.2: Section through the divided rotor in the casing (new concept)

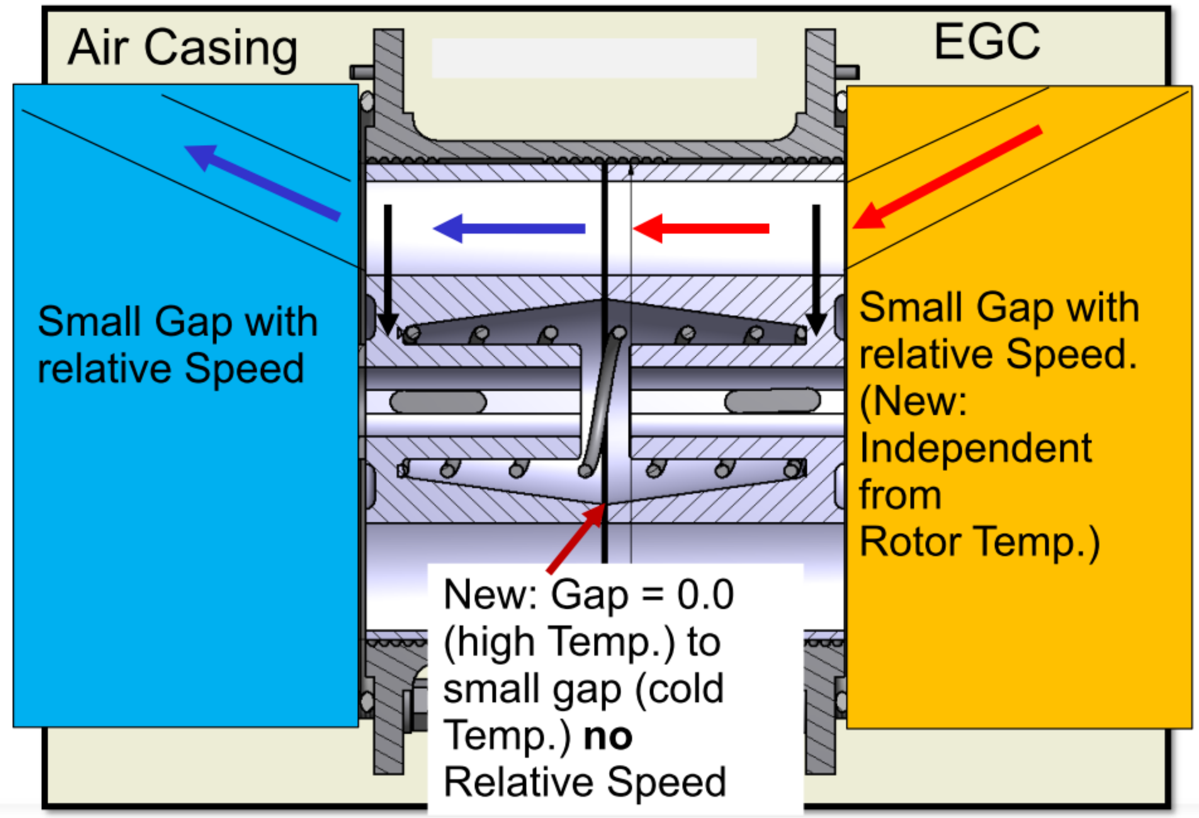

Figure 2.3: gaps with the divided rotor in the casing (new concept)

Large gaps between the rotor and the housing can lead to lower efficiency. Therefore, small gaps are necessary to ensure that the PWS functions properly [8]. The efficiency decreases exponentially as larger as the gaps are. The gap in the middle is a little bit different regarding its influence on the system. If one looks at the states from cell to cell in the middle gap, the states are very similar and only slightly delayed (0.1389 msec, at 12000rpm with 36 cells). The pressure drops are not so large across the flow direction and there is also no possibility, that exhaust gas or air can flow directly into the respective low-pressure process. Whether on air or gas side, as it is possible between the rotor and the housing. The quantity of flow coming out of one cell flowing into the next cell is not lost. There is only a small exchange (shift) from cell to cell. In the overall balance, the rotor area is therefore quite dense, although it is not made from one piece.

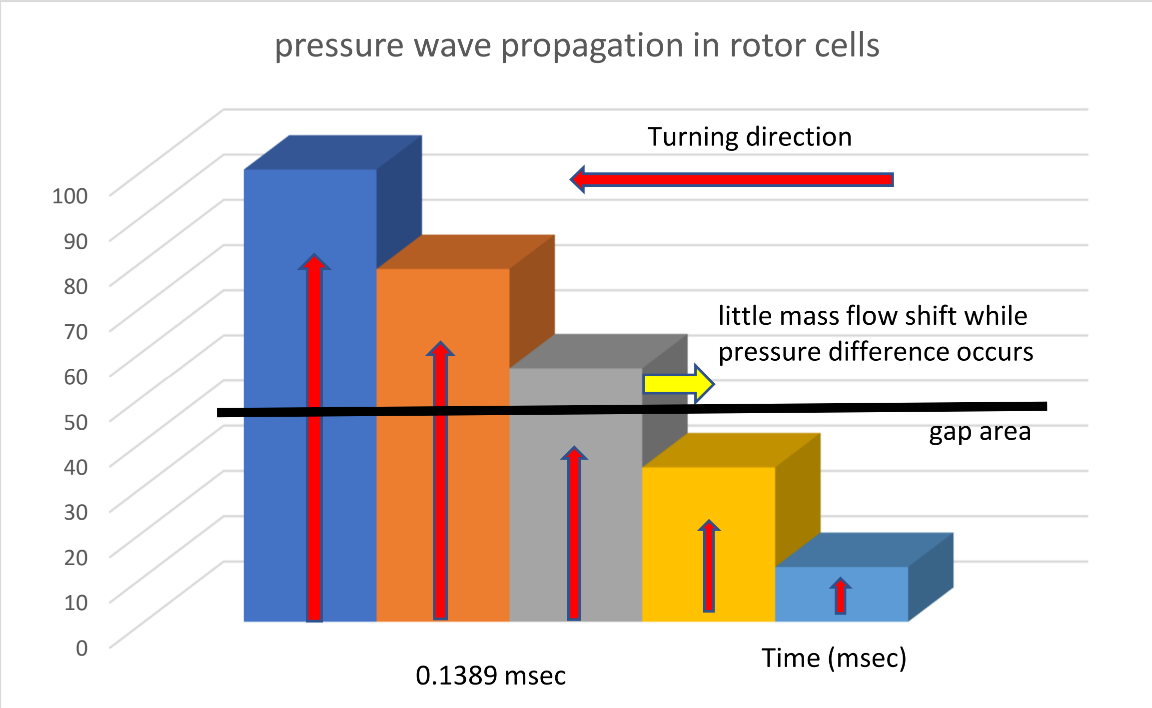

Figure 2.4: Simple schematic representation of the conditions in the rotor gap (new concept)

As soon as the rotor gets hot, the gap closes almost completely. This will be done faster, as with the old concept. Only half of a rotor have to be heated up and both rotor halves must never really come into contact. Coming back to the bearings again. In the old concept, a spindle bearing was used which could not be encapsulated. This also led to the fact, that hot exhaust gas blew the grease out of the bearings, which subsequently failed. With the new concept is this impossible. Hot exhaust gas cannot flow through there and the bearings themselves are fully encapsulated.
Another important advantage of the new concept is, that the charger has better conditions during cold start now, since no time is lost until the rotor gets hot and the large gap on the exhaust side closes. With the old concept, this was the case and required a certain waiting time, the PWS did not work well as long as the exhaust gas temperature stayed under a certain level. Means with the new PWS system the boost pressure can be build up faster now.
To handle that, a cycle switch was implemented in the new concept. This means, that one of the two gas dynamic cycles can be switched off, similar to a sequential charging

system. With the old concept, both cycles were always applied, which had an unfavorable influence on the gas dynamics with small throughputs and consequently caused to use a twisting of the air-side control edges.
This was realized either by turning the entire air housing or by means of a round plate with the control edges inside the air housing. It is inevitable that this solution involves further losses such as secondary flows behind the plate or unfavorable flow conditions between the rotatable plate and the air housing. There are no such losses when one cycle is switched off and one cycle runs roughly as if the charger runs with two open cycles and twice the throughput. For this reason, the elaborate twisting of the control edges has been dispensed within the new concept.

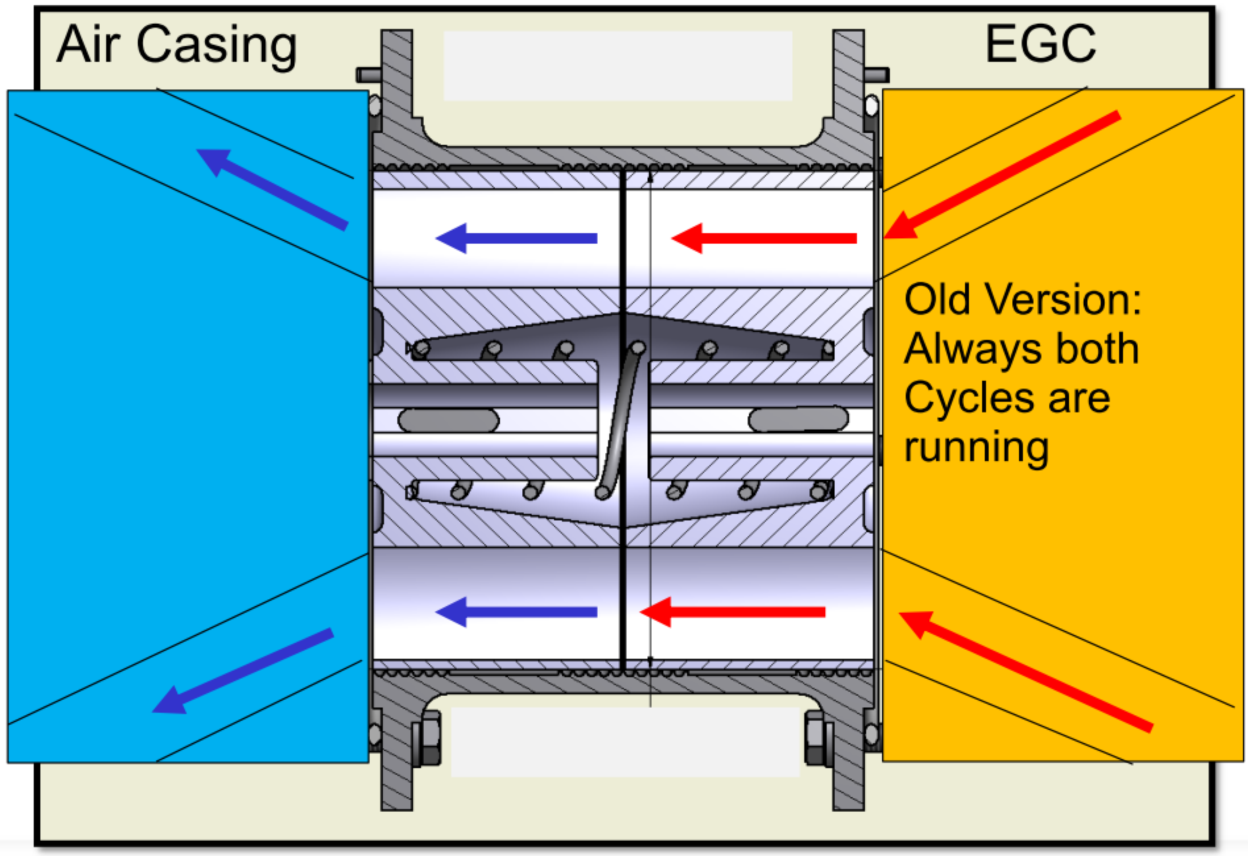

Figure 2.5: Scheme without cycle switch (old concept)

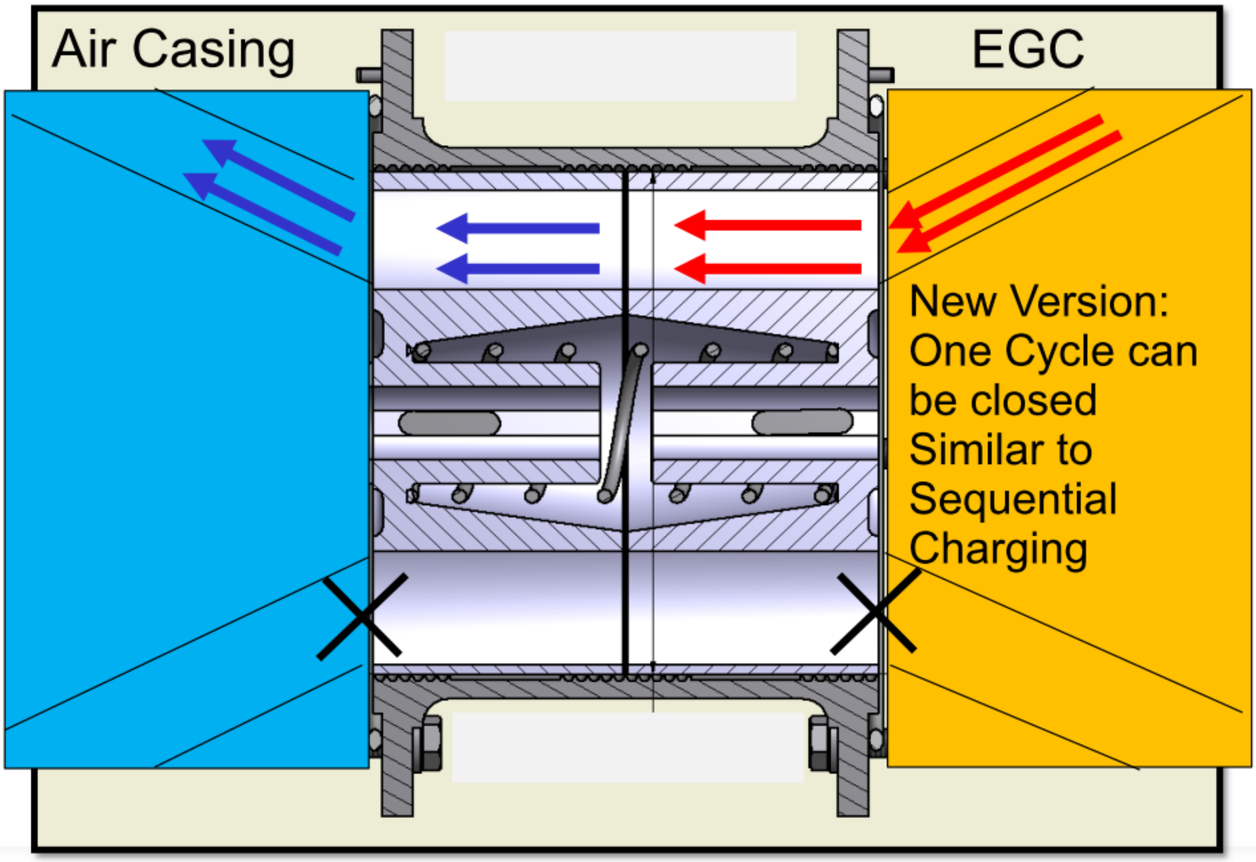

Figure 2.6: Scheme with cycle switch (new concept)

It is sufficient to set one suitable twist angle. This can be determined in advance with a simulation but can also be readjusted on the engine. When switching off one cycle, it is important to note, that the rotor speed must be kept at the same level that exists with twice as much throughput running with both cycles. In practice, this causes-, that the supercharger can basically be operated at approximately the same speed level; rapid acceleration of the rotor in order to follow a rapidly accelerating internal combustion engine is not necessary. Therefore, the drive motor of the PWS can have a smaller Power output than with the old concept.

Furthermore, the water cooling of the exhaust gas housing has the advantage that the housing no longer bends, which in the old concept led to leaks and pinching of the long control shaft for the variable gas pockets. The new control shafts are much shorter, and the housing no longer bends itself. Even O-rings can be installed for sealing, which was previously impossible.

Due to the easily reproducible gaps, the performance of each PWS built in series with the new concept is practically the same, which is very important for the application on the respective engine.

All these points contribute conceptually to bring the PWS much closer to series production than before.

Table 2.1: New Comprex concept versus old one briefly

	Comprex Concept	old	new	Rating new concept
1	**Water cooled aluminium exhaust gas casing**	**no**	**yes**	**+++**
2	**Cycle shift (sequential boosting system)**	**no**	**yes**	**+++**
3	**Splitted rotor**	**no**	**yes**	**+++**
4	**Capsuled bearings**	**no**	**yes**	**++**
5	**Individual variable gas pockets with engine break**	**no**	**yes**	**+++**
6	**No Edge shift**	**no**	**yes**	**+++**
7	**Casing geometries not influenced by temperatures**	**no**	**yes**	**+++**
8	**Electric drive**	**yes**	**yes**	**o**
9	**Small speed variation (no strong e-driver needed to accelerate)**	**no**	**yes**	**++**

3. Real Hardware Prototype Measurements

So far, only the thermodynamically basics of the new PWS have been demonstrated, but there are already prototypes that have been subjected to tests. In [2] (Binder E. Untersuchungen zum Potential eines Verbrennungsmotors mit Druckwellenlader), the PWS and its basic functions are described very nicely and measurements on the hot gas test bench, measurements from the engine test bench as well as simulations are presented. The advantages of the PWS are shown, but also various disadvantages are covered, which are largely due to the old concept and an unfavourable rotor design in this specific PWS. Lessons were therefore drawn from existing experience and, as just described, a new design from Antrova AG was launched. The measurements carried out in [2] on the hot gas test bench, however, require the knowledge that the high-pressure path was not in a closed loop. Therefore, m_3, i.e. the mass flow at the hot gas inlet, has been specified there as a reference value for the throughput.

But one point is very important for relevant measurements on the hot gas test bench and must be observed. In contrast to a turbocharger measurement, the PWS itself must provide the amount of gas at the hot gas inlet for meaningful measurements. This can be done by providing a closed high-pressure path between the charge air outlet (m_2) and the hot gas inlet (m_3). In any case, m_3=m_2+m_fuel applies.

Since the commercially available hot gas test benches are not intended for such a measurement. The desired path decoupled from the technical conditions of the combustion chamber can be realised by using a hot gas heat exchanger (HWT). The maximum gas inlet temperatures at the PWS are limited to approx. 660°C with the HWT, but this is not particularly disturbing in this context. A roots blower then ensures the circulation in the high-pressure path. Without this measure, m_2 is significantly smaller than m_3 due to the necessary throttling. The measurements may serve for relative comparisons or mechanical tests but are not really representative when it comes to the real thermodynamic data or the torques on the rotor. Furthermore, the precise rotor gaps must be measured and documented before each test run.

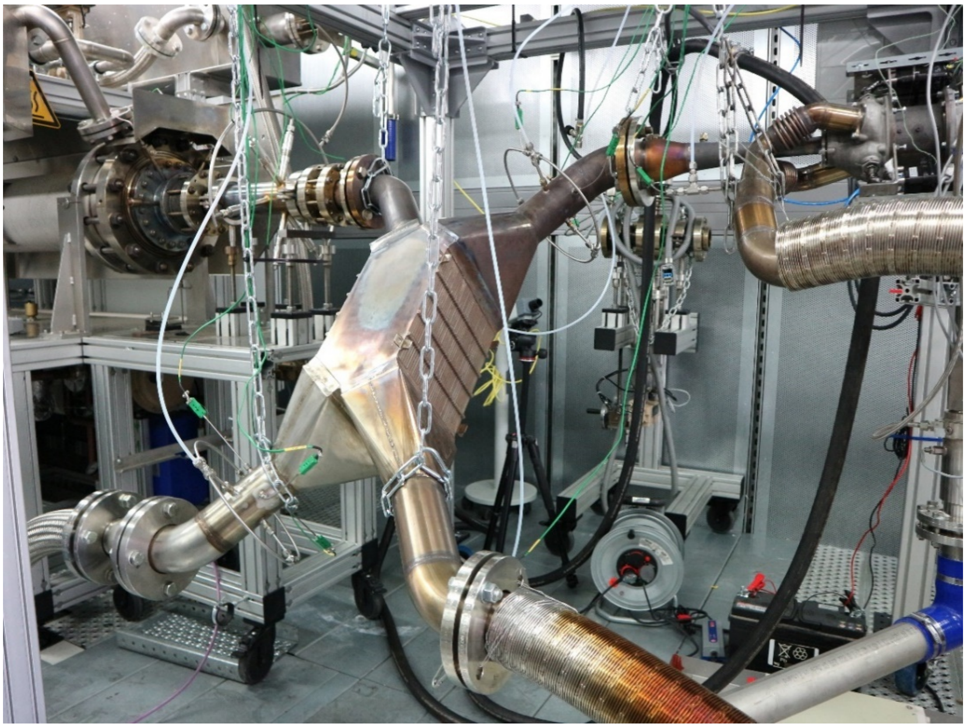

Figure 3.1: The heart of the hot gas measurement is a high-temperature-resistant hot gas heat exchanger (HWT) (photo: measurement on turbocharger test stand ICT Karlsruhe 2018).

These measurements showed that the PWS is on a promising path with the new concept. It is also important to ensure that there are no turbocharger standards with regard to pressure losses, especially in the low-pressure range of the PWS. As expected, high levels of efficiency are possible.
In addition to the pure performance of the PWS, the question of the influence of the center gap between the two rotor halves was interesting. The difference in boost pressures was therefore measured with a larger and a smaller center gap of the rotor. This influence was investigated with a relatively small mass throughput of 0.035kg/s and also with no particularly high temperature at the hot gas inlet of only 400°C. The resulting volume flow should be so high that some boost pressure is generated (approx.1.6 bar abs) but not so high that the influence can hardly be measured. In order to estimate the influence of the gap, a comparison was made between the pressure on the hot gas side p3 stat and the boost pressure p2 stat. If the gap was reduced by 0.3mm, the difference between these two values only decreased by 9.7mbar in favor of the small gap, which confirms the theory that the performance of the charger is not as sensitive to the center gap as it is to the column on the edge of the rotor.

4. Summary and Outlook

With all the advantages shown in terms of the overall performance and durability, the Comprex™ PWS can be a real alternative to further reduction of emissions and fuel consumption. The new concept has a high potential to solve all existing drawbacks of the older PWS concept. Significantly in the terms of new legislations, but with increased driving pleasure on top of it.

Especially for hydrogen engines and their needs the Comprex™ appears like a symbiosis with the engine to reach new benchmarks and even save costs on the boosting device part.

Generally, the Comprex™ designed according to the new concept for automotive applications, with cooled hot gas housing, split rotor and cycle switch, can be used with advantage for small gasoline and gas engines. Here it is becoming increasingly difficult for the turbocharger to achieve sufficiently high efficiency levels and manage the balancing act between good dynamic response and high nominal power.

However, this does not mean, that there is no attractive application for large internal combustion engines with Comprex™ to be designed accordingly. Especially, future Hydrogen engines for Cars and Trucks are an interesting field for a Comprex™ application. It is pleasing that the user is charged fewer overall costs for a Comprex™ to fulfil the measures required by laws, such as e-boost, VTG and or two-stage or sequential charging do. But those would cost substantial more.

Antrova AG has 17 years experience to build any Comprex™ pressure wave supercharger size in terms of layout, testing and matching it to an existing combustion engine, let's tackle it.
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