**IMECE2004-59022**

# RADIAL-FLOW WAVE ROTOR CONCEPTS, UNCONVENTIONAL DESIGNS AND APPLICATIONS

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## ABSTRACT

Wave rotor technology has shown a significant potential for performance improvement of thermodynamic cycles. The wave rotor is an unsteady flow machine that utilizes shock waves to transfer energy from a high energy fluid to a low energy fluid, increasing both temperature and pressure of the low energy fluid. While several different configurations of mainly axial-flow wave rotors have been studied in the past, its four-port version with straight channels has been used most widely. During the past century, extensive experimental and numerical efforts have been performed on such conventional designs. This study introduces a new radial-flow configuration that can be employed in several novel designs. Advantages and challenges of such designs are outlined. Feasible implementations of these arrangements into gas turbine engines are shown and a new rotor speed controlling system is described, too.

Keywords: *radial wave rotor, comprex, internal combustion wave rotor, shock waves, gas turbine,*

## INTRODUCTION

The potential of unsteady-flow wave machines for performance enhancement of thermodynamic cycles has been recognized, but often neglected until recently. Shock tubes, shock tunnels, pressure exchangers, pulse combustors, pulse detonation engines, and wave rotors are the best-known wave devices developed so far. Different to reciprocating machines and turbomachinery that employ mechanical parts like pistons and blades to accomplish compression or expansion processes, unsteady-flow devices utilize compression and expansion waves for various applications. It has been proved that for the same inlet and outlet Mach numbers the pressure gain in time-dependent flow devices can be much greater than in steady flow devices [1, 2], which may be a driving reason for using unsteady wave machines. Their geometry can be very simple like that of a straight tube, since the mechanical parts only house and control the wave process. Hence their manufacturing cost can be low. In this work attention is given to wave rotor machines.

## WAVE ROTOR MACHINES

Wave rotor machinery represents a promising technology that can enhance cycle power and efficiency, plus possibly reduce the overall size, weight and cost. It allows a higher cycle peak temperature without need for a cooling system. Furthermore, the rotational speed of a wave rotor is low compared with turbomachines. This results in low material stresses, which may allow for higher material temperatures or the use of less expensive materials.

The essential feature of a wave rotor is an array of channels that is arranged around a rotational axis. The channels may be axial, radial or oblique to the axis. They may be straight for simplicity or curved in more advanced designs. Likewise, the cross-sectional area and form of the channels could be constant in simpler designs and may be varied in advanced configurations. The channels are incorporated in a drum, disc or a cone, that usually rotates between two stationary end plates as shown in Fig. 1 for an axial configuration. The end plates have ports that direct flow into and out of the channels and connect the wave rotor through manifolds to the external continuous flow process. The relative motion between ports and channels controls the unsteady flow through the channels. The number and position of the ports varies for different applications. The gap between the end plates and the channel assembly has to be relatively small to minimize leakage losses. This may be ensured by a passive or active gap control or by contacting surfaces that are made of appropriate sealing material. While in the most applications the channel assembly rotates and the end plates are stationary, the opposite configuration has been suggested in which the channels are stationary and the end plates with port openings rotate, ensuring the same flow control mechanism. Such a configuration has more than one rotating part and usually doubles interfaces that need to be sealed between rotating and stationary parts. However, it may be preferred for laboratory investigations because it easily enables flow measurement in the channels where the important dynamic interactions take place. However, this arrangement rarely seems to be convenient for commercial purposes.

The rotating parts may be gear or belt driven or preferably direct driven by an electrical motor. The power required to keep them at correctly designed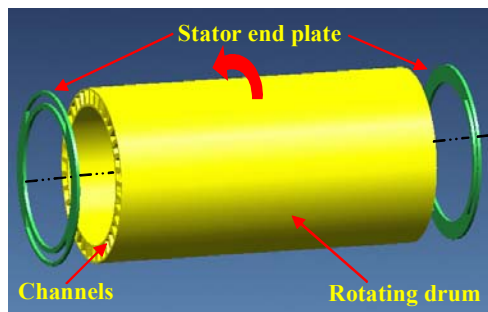 speed is negligible [3, 4]. It only needs to overcome rotor windage and friction in the bearings and contact sealing if used. Alternatively, rotors can be made self-driving. This configuration, known as the "free-running rotor", can drive itself by using the momentum of the flow to rotate the rotor [5, 6].

The periodical exposure of the channels to the port openings in the end plates initiates compression and expansion waves that move through the wave rotor channels and generates the unsteady flow internally in the wave rotor. Thus, pressure is exchanged dynamically between fluids utilizing unsteady pressure waves. Therefore, unlike in steady-flow turbomachines that usually in one component only compress or expand the fluid, both compression and expansion are accomplished in the wave rotor, being a single component.

Through the periodic exposure of the channels to both fluids between which the pressure is exchanged, the channel wall temperature is maintained between the temperatures of both fluids, which gives the wave rotor an inherently self-cooling feature. Further, the velocity of the working fluid in the channels is about one-third of values within turbomachines [4]. Therefore, the rotor channels are less prone to erosion damage than the blades of turbomachines.

If most of the fluid leaves the wave rotor channels in a direction opposite to that in which it has entered, then such a configuration is usually referred to as the reverse flow-type and if most of the fluid is flowing through the full length of the channel and leaving at the other end then this is called the through-flow type.

## WAVE ROTOR APPLICATIONS

As a combined expansion and compression device, the wave rotor can be used as a supercharging device for IC engines, a topping component for gas turbines, or in refrigeration cycles. In advanced configurations, the high energy fluid may be generated by combustion occurring internally in the wave rotor channels allowing extremely short residence times at high temperature, hence potentially reducing emissions. A condensing wave rotor may be viewed as a similarly advanced configuration that enhances the performance of refrigeration cycles. Recently, wave rotor technology has been envisioned to enhance the performance of ultra-micro gas turbines manufactured using today's and future microfabrication technologies [7, 8].

### Gas Turbine Applications

For gas turbine applications, in a conventional arrangement, a wave rotor is embedded between the compressor and turbine "parallel" to the combustion chamber. Figure 2 illustrates how a four-port wave rotor is used to top a gas turbine cycle. In the wave rotor channels, the hot gas leaving the combustion chamber compresses the air coming out of the compressor. After the additional compression of the air in the wave rotor, it is discharged into the combustion chamber. The burned gas expands during the compression of the air and is afterwards scavenged toward the turbine. Then, the channels are re-connected to the compressor outlet, allowing fresh pre-compressed air to flow into the wave rotor channels and the cycle starts again. Due to the pre-expansion in the wave rotor, the burned gas enters the turbine with a temperature less than
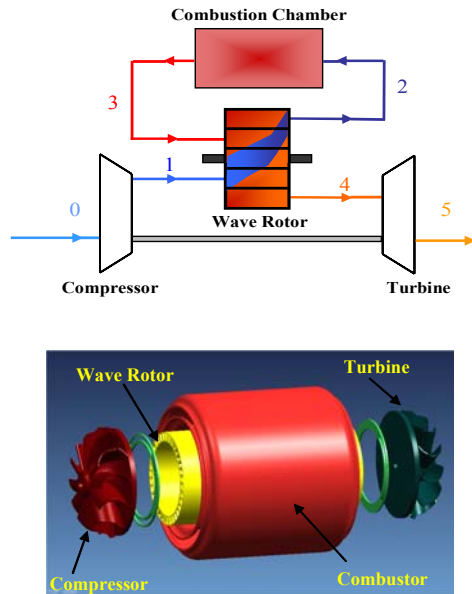


**Figure 1:** Schematic configuration of a typical wave rotor machine

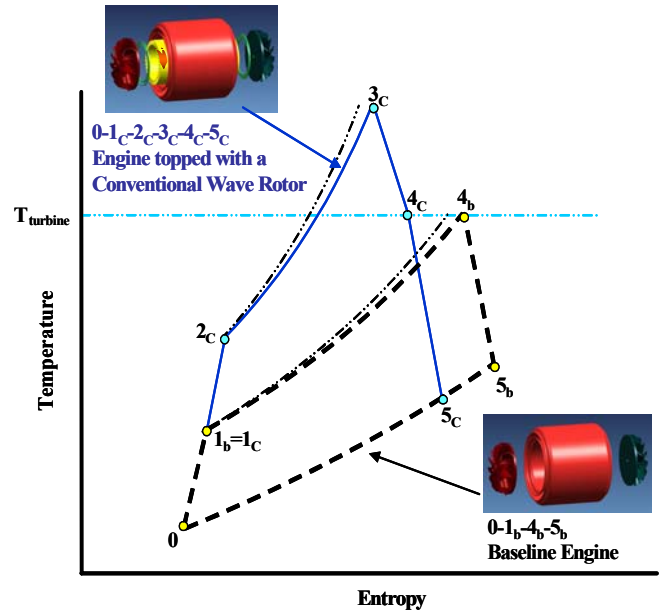**Figure 2**: Schematic of a gas turbine topped by a four-port wave rotor



**Figure 3:** Schematic Temperature-Entropy diagram for a gas turbine with and without a wave-rotor

the combustor exit temperature. However, the gas pressure is higher than the compressor exit pressure by the pressure gain obtained in the wave rotor. This is in contrast to the untopped engine, where the turbine inlet pressure is always less than the compressor discharge pressure due to the pressure loss occurring in the combustion chamber.

The general advantage of using a wave rotor becomes obvious when comparing the thermodynamic cycles of baseline and wave-rotor-enhanced engines. Since the wave rotor application was first envisioned and tried for gas turbines [9], this is demonstrated in a schematic temperature-entropy diagram for a gas turbine baseline engine (dashed line) and the corresponding wave-rotor-topped engine (solid line) in Fig. 3. While many other advantageous implementation cases of the wave rotor into a given baseline engine are possible [10, 11]. The diagram shows that both the baseline and the enhanced cycle gas turbine are operating with the same turbine inlet temperature and compressor pressure ratio. However, the output work of the topped engine is higher than that of the baseline engine due to the pressure gain across the wave rotor. In the shown case the amount of heat addition is the same for both cycles. Therefore the thermal efficiency for the topped engine is higher than that of the baseline engine, which is indicated by the lower entropy production in the wave-rotor-enhanced cycle.

Wave rotors as topping devices for gas turbine cycles have been studied extensively. Since the early 1960s General Electric Company (GE), General Power Corporation (GPC), and Rolls Royce were involved in the development of wave rotor prototypes for propulsion applications [12, 13]. Mathematical Science Northwest (MSNW) also studied various aspects of wave energy exchange and proposed a wave rotor

design for an aircraft turbofan engine [12]. In the 1980s, different US agencies like Defense Advanced Research Program Projects Agency (DARPA) and the US Navy expressed interest and sponsored programs to develop an understanding of wave rotor science and technology. Many developments were presented in the 1985 ONR/NAVAIR Wave Rotor Research and Technology Workshop [13].

Since the late 1980s, A large research program at NASA Glenn Research Center (GRC) collaborated by the US Army Research Laboratory (ARL) and Rolls-Royce Allison has aimed to develop and demonstrate the benefits of wave rotor technology for future aircraft propulsion systems [14-20]. Experimental studies at NASA on four-port [21] and three-port [22-24] wave rotors enabled the estimation of loss budgets [25, 26] and simulation code validation [27]. The experimental work consisted of two phases. Initially, a simple three-port flow divider wave rotor was built and tested to evaluate loss mechanisms and calibrate the simulation code. Next, a four-port pressure exchanger was built and was tested to evaluate the pressure-gain performance for application to a small gas turbine (Allison 250). However, a study by Rolls-Royce Allison indicated that thermal loads on the rotor and ducting predicted for the NASA wave rotor cycle in real engine conditions may be difficult to manage. In response, Nalim and Paxson [28, 29] proposed an alterative cycle with a combustor bypass significantly lowering thermal loads. Sealing and mechanical design issues are being addressed in current NASA tests.

NASA's wave rotor research was later extended to the concept of internal combustion wave rotors [30-33] in which both pressure exchange and combustion take place within the wave channels, and further to pulse detonation engines (PDE)

taking advantage of constant-volume combustion for higher performance and better efficiency [34-37].

In a recent study, Akbari and Mueller have performed a thermodynamic analysis to calculate the thermal efficiency and specific work of two unrecuperated microturbines (30 and 60 kW) topped with a four-port wave rotor. The engines manufactured by Capstone Turbine Corporation have been widely used recently and efforts are currently being persuaded to increase their performance considerably. The results have predicted overall thermal efficiency and specific work enhancement up to 34% for the smaller engine and 25% for the larger engine, using a four-port wave rotor with a compression ratio of 1.8 [10]. The general performance maps obtained by the authors clearly have demonstrated the considerable performance enhancements of small gas turbines through use of wave rotors. Similar approach has predicted an improvement up to 15% of overall efficiency and specific thrust in a turbojet engine using the wave-rotor-topping cycle of the 30 kW microturbine flying at an altitude of 10,000 m at Mach 0.8 [11].

### Car Engine Supercharging

Wave rotors have been commercially used for IC engines as a replacement for conventional supercharges or turbochargers. Brown Boveri Company (BBC), later Asea Brown Boveri (ABB) and now Alston, in Switzerland has a long history in wave rotor technology. As reported by Meyer [9], the first successful wave rotor was tested in the beginning of 1940s as a topping stage for a locomotive gas turbine engine based on patents by Claude Seippel [38-41]. The first wave rotor was not used commercially, mainly because of its inefficient design and crude integration [42]. Later, BBC decided to concentrate on the development of pressure wave superchargers for diesel engines, due to their greater payoff compared to other applications [12]. By 1987, the first wide application of the Comprex® in passenger cars occurred in the Mazda 626 Capella [5, 43]. Since then, ABB's Comprex® pressure wave supercharger has been commercialized for several passenger car and heavy diesel engines. The Comprex® has also tested successfully on vehicles such as Mercedes-Benz diesel car [6], Peugeot, and Ferrari [12]. The main advantage of the Comprex® compared to a conventional turbocharger is its rapid response to changes in engine operating conditions. Furthermore, as the efficiency of the Comprex® is independent of scale, its light weight and compact size make this device attractive for supercharging small engines (below about 75 kW or 100 hp) [44, 45].

### Refrigeration Applications

Wave rotors also have been used for air-cycle refrigeration systems [4, 42, 46]. Power Jets Ltd in the U.K. utilized wave rotor technology in the design and development of two prototype air-cycle refrigerators used for environmental cooling purposes. The prototypes were installed and employed in gold mines in India and South Africa and performed the same duty as equivalent vapor-cycle machines, but with lower weight and bulk.

Recently, a unique and cutting-edge application of wave rotors in refrigeration cycles using water (R718) as a refrigerant has been studied [47-50]. In fact, the wave rotor implementation can increase efficiency and reduce the size and cost of R718 units. A three-port wave rotor has been introduced as a condensing wave rotor that employs pressurized water to pressurize, desuperheat, and condense the refrigerant vapor - all in one dynamic process. Besides, giving the possibility of an additional rise of the vapor pressure, the condensing wave rotor eliminates the need of a bulky condenser because full condensation occurs inside the rotor channels. Furthermore, adding a condensing wave rotor to a water refrigeration cycle allows for a lower pressure ratio of the compressor, which is crucial for the R718 chiller technology.

### RADIAL WAVE ROTOR

For all the above applications, so far most widely axial-flow wave rotors have been used and investigated. Pure scavenging is a challenging task in the axial-flow configurations. In fact in gas turbine applications, through-flow configurations recirculate some portions (30 to 50%) of once-burned gas to the combustion chamber [16]. Even though reverse-flow configurations can deliver pure compressed air to the combustion chamber, a buffer layer can remain in the channels. This residuum can remain permanently in the channels. Repeated compression waves increase the temperature of this buffer layer. This leads to high wall temperatures in the center of the channels [29]. It is possible to achieve a full scavenging process for both through and reverse-flow configurations using bypassing or bleeding of certain mass flows [28, 29, 51]. However, all of this leads to more complex configurations.

Jenny and Bulaty [52] have introduced a conical wave rotor with oblique channels in which a radial component is added to the axial flow. However, the flow still enters and leaves at the front and rear end respectively and predominantly in axial direction.

Here the radial-flow wave (wave disks) concept is introduced employing a flow in the radial and circumferential directions. This can substantially improve the scavenging process by using centrifugal forces. Figure 4 shows schematically a simple radial-flow wave rotor with straight channels and a constant rectangular cross-sectional area. As Fig. 5 suggests, the channels alternatively may be curved and varied in cross-sectional area. Compared with straight channels,
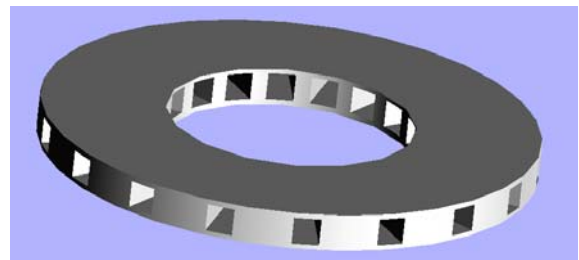


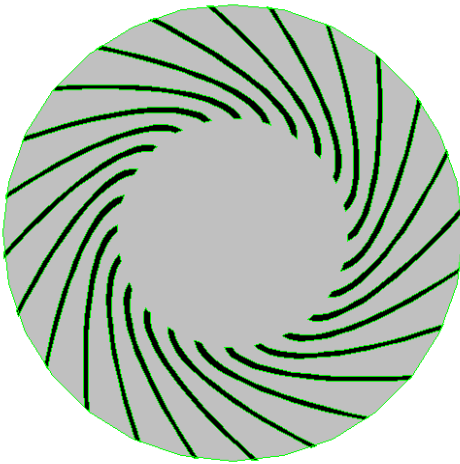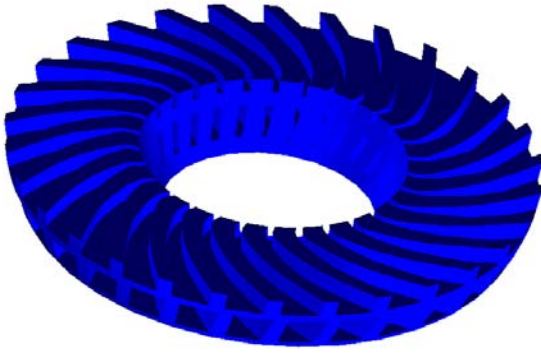**Figure 4:** Radial-flow wave rotor with straight channels

**Figure 5:** Radial-flow wave rotor with curved channels



**Figure 6:** Centrifugal acceleration in straight and curved channels of radial wave rotors

curved channels provide a greater length for the same disc diameter, which can be important to obtain certain wave travel times for tuning. With curved channels also the angle against the radius can be changed freely. This allows modulating of the inflow direction acting accelerating component of the centrifugal force (see Fig. 6) and also to choose the inlet and outlet angle independently. The latter enables independent matching with the flow direction through the stationary inlet and outlet ports or the use of a freely chosen incidence angle
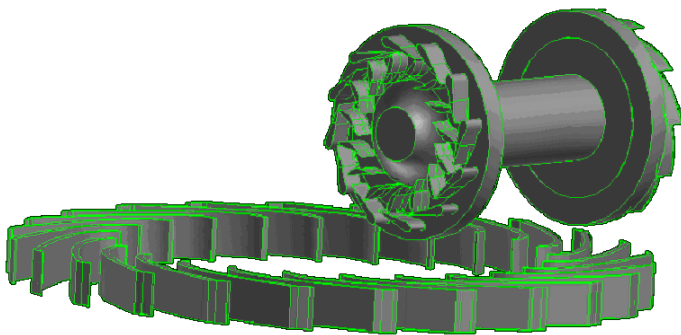
for a self-driving configuration. Furthermore, curved channels may be more effective for self- propelling and work extraction in the case of a wave turbine or work input for additional compression, analogous to the principle of turbomachines.

For gas turbine applications, the compressor and turbine can remain as a unit as shown in Fig. 7 with its axis perpendicular to the wave disc. However the angle can be arbitrary.

### Radial Internal Combustion Wave Rotor

Positioning the combustion process internally in the wave rotor can simplify the porting enormously. Furthermore, an internal combustion configuration is especially attractive for a radial wave rotor in a gas turbine. In such an envisioned configuration, the pre-compressed air from the compressor enters the wave disc through the inner end plate ports and through the outer end plate ports the flow is then directed to the turbine, allowing still a relative positioning as shown in Fig. 7. The internal flow and combustion process in a wave disc is shown schematically in Fig. 8 for a disc with curved channels. The fuel supplies (green) are located at the inner inlet port. The mixture in the channel is then ignited by either a stationary igniters that act through holes in the channel (yellow in the middle of the channel) or by rotating electrical igniters that are activated only in a certain angular position of the mixture filled channel. It is possible to radially stratify the air-fuel mixture
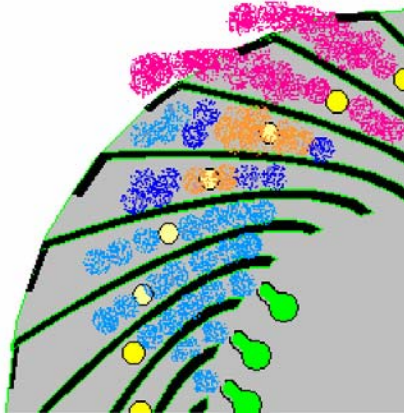


**Figure 7:** Relative position of turbo-compressor with respect to a wave disc
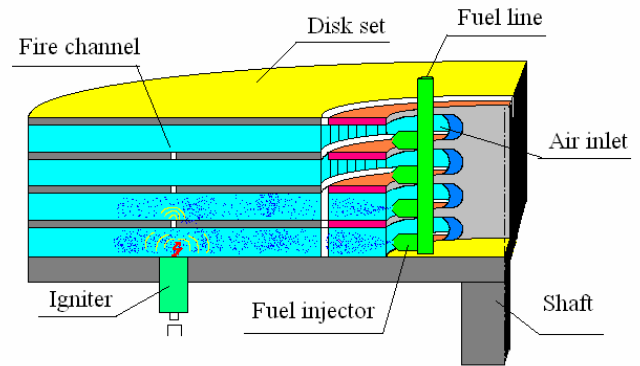
**Figure 8:** Internal combustion wave disc



**Figure 9:** Multi-disc internal combustion wave rotor

during the channel filling process. For example, after closing the channel from both sides, rich mixture could be trapped in the middle of the channel and ignites while at the channel ends lean mixture or air present. This can keep the channel ends cool, provides sealing and prevents dangerous mixture leakage.

The combustion process starts in the central part of the channel, where the fuel/air mixture is rich and flame propagates to inner and outer end of the cell. Since heat release increases pressure inside the channel, opening the outer channel end generates an outflow of the exhaust gases. For curved channels, torque is given to the disc during the flow scavenging. This can be used for self-driven rotation or if large enough for external work extraction through a shaft or a generator. The outflow of the burned gases can induce an inflow of air and air-fuel mixture into the channels, refilling and cooling the cell before the cycle starts again. Additionally, this cycle can be self-aspirating without need for an external turbomachinery if the combustion is a detonation like in a pulse detonation engine. This way the internal combustion wave disc can be also considered as an attractive propulsion system and may be used as a simple jet engine even without expensive turbomachinery. Such a propulsion device would have a small and most important a flat frontal area.

### Condensing Radial Wave Rotor

The radial principle offers great potential and advantages for the condensing wave rotor. It allows exploiting the enormous density differences of gaseous and liquid fluid by the action of centrifugal forces. This supports greatly the separation of vapor and condensed fluid in the scavenging process and channel drying before refilling, addressing a core problem in handling the phase change in the wave rotor occurring in both direction.

### STACKED WAVE DISCS

The wave disc described above can also be stacked together as shown in the upper part of Fig 5. This way a modular construction is possible that can be adapted for designs with different mass flow rates. Furthermore, analogoud to the known two-row axial Comprex, the channels are subdivided, which can allow for acoustic noise reduction. Such a wave disc

stack can be used in the same way as a single disc wave rotor shown in Fig. 7, with the additional advantage that some discs may be shut off easily by closing their ports. This can make it easy to adapt for various flow rates in one application while widely pertaining the same wave pattern inside the active wave discs.

Such a pressure exchange wave disc stack can be used for applications like refrigeration, gas turbine topping and supercharging of IC engines. The stacking discs configuration can also be used for internal combustion wave rotor designs. Figure 9 shows how additionally an adaptation to a load can be obtained by simply switching on and off parts of the stack. On the other hand, for a quarter of power only one disc is fuelled, for half of the power two discs, and so on. On-combustion channels can transfer hot gases from one disc to the neighbouring disc, initiating ignition there if this disc is fuelled too. Alternatively, a laser beam can be sent through the holes between the discs initiating ignition in fuelled discs, which then do not need to be adjacent to each other. Instead of shutting off and on the fuel supply to discs, the fuel injector can be also electronically controlled for fuel mixture stratification and smooth load control within the range limited by the oxidiser presence in each disc.

Stacked wave discs also provide the unique opportunity to place a radial-flow turbomachinery at the periphery of the axis of the wave disc stack with an angle such that the turbomachine impeller periphery interfaces all active discs of the stack. This way a peripheral continuous outflow from turbomachine impeller and inflow to the disks is possible without any additional ducting, collector, volute, diffuser or nozzle between the turbomachine impeller and the wave rotor. Ducting losses are eliminated, resulting in a higher efficiency of the assembly. Figure 10 shows a configuration in which a radial compressor is placed inside a wave disc stack. Only the inner plate is placed between the impeller and the inner wave rotor. Due to the angle between the axes of the impeller and wave rotor, the end plate between both can be spherical for minimum thickness (ducting length). This also allows switching on and off outer discs by varying the angle between impeller and wave rotor
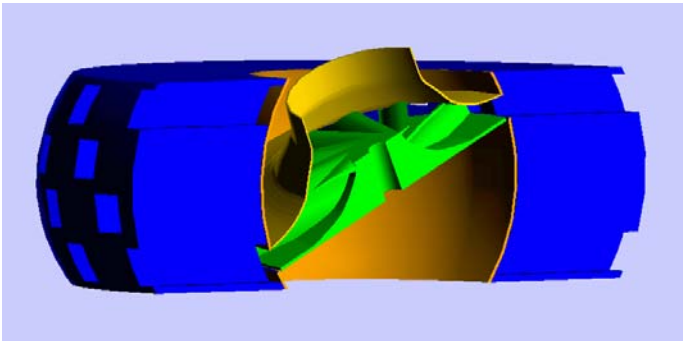
**Figure 10**: Stacked radial wave discs and radial compressor



**Figure 11:** Cut-view of a radial wave rotor topping a gas turbine

axis. The port opening can be a continuous oblique slot that interfaces with the impeller periphery. Since the end plates are stationary, they can form one part with the housing of the turbo impeller as clearly shown in Fig. 10 for the outer impeller shroud and axial duct. The shape at the outer diameter of the wave rotor stack is generated by the shape at the inner diameter, the channel length, inclination and timing of each disc. Still if the outer shape is similar to the inner shape of the wave disc stack, the timing on each disc is different and is determined by the circumferential distance from one port to the other at the inner diameter, as shown schematically in Fig. 10.

In gas turbine application preferably the turbo-compressor impeller is placed inside the wave rotor. Such a design eliminates the need for a diffuser which has been replaced by a more effective shock deceleration process [1, 2] in the wave disc channels. Using an outwards-flow turbine, the turbine could be placed at the outer diameter with its axis also set at an angle to the wave rotor axis but rotating around the wave rotor axis with respect to the compressor axis, allowing a certain time between opening the channels at the inner and outer diameters. Such a configuration might be too challenging and would require separate shafts for compressor and turbine. To avoid a gear box, their coupling could be achieved electrically with generator and motor. Figure 11 shows a simpler configuration with a direct shaft coupling compressor and turbine as in a gas turbine. This requires a flow collector from the wave rotor outer end plate and certain ducting that directs the flow to the turbine as shown in Fig. 12. Figure 13 shows an exploded view of such a configuration. The outer end plate is shown with an oblique slot as it would also be suitable for a peripherical outer radial outflow turbine. However, for an external turbine like shown here the slot of the outer end plate can have any form that will adapt most consistently to the outlet opening time. In Fig. 11, 12, 13 a turbine volute is used to distribute the flow around the turbine. The exhaust gas leaves the turbine axially.

The configurations shown in Fig. 11, 12, 13 work best with an internal combustion wave rotor that allows for outward flow only in the wave rotor. If a conventional external combustor is used, than an additional port opening is necessary for the burned gases leaving the combustor and the high pressure air entering the combustor. External ducting may be
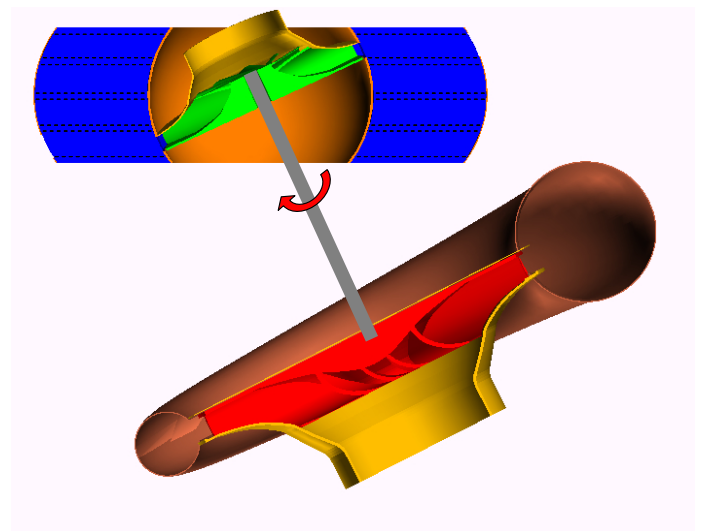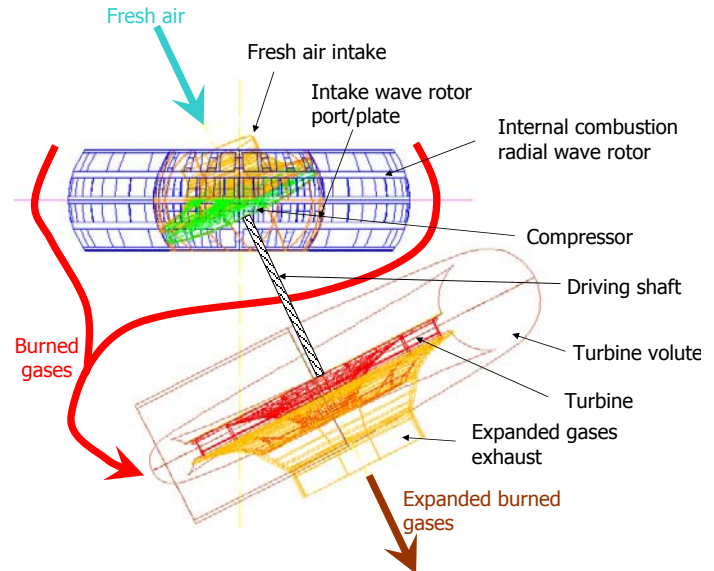


**Figure 12**: Flow through an internal combustion radial wave rotor

eliminated by having combustion in the pressure exchange channels. Diamond shaped cross sections may allow for more space between the channels and also a more rapid opening and closing of the channels by an oblique port slot as shown schematically in the upper part of Fig. 14. This avoids flow barriers at the corners of the channels as they appear with rectangular shapes and an oblique slot as shown in the lower part of Fig. 14.

Finally, the configuration of stacked wave disc with an internal turbo-compressor appears also very attractive for a condensing wave rotor in refrigeration or heat pump applications.

**Figure 13:** Component parts of a radial wave rotor topping a gas turbine

5. compressor inlet port
4. radial compressor
3. internal end plate
2. external end plate
1. Stacked radial wave rotors
6. turbine volute
7. turbine
8 turbine exit port



end plate port

**Figure 14:** Different channel cross-sections for stacked wave discs

## AERODYNAMIC SPEED CONTROL

The wave rotor operation depends strongly on the timing of the port opening and closing relative to the traveling time of compression and expansion waves within the wave rotor channels. In tuned conditions these waves arrive at certain locations tuned with the opening and closing of the ports. However, changes in engine operation conditions affect the tuning. Designing wave rotors that are tuned in a wide range of operation has been a major challenge. Passive and active control mechanisms have been used to address this problem.

A typical passive control method is to use pockets located in the end plates that control wave reflections to achieve good performance during off-design operations. In fact, the pockets adapt the wave pattern to changes in operation conditions. Therefore, the pockets reduce the sensitivity of the wave rotor to engine speed changes.

A controlled bypass method is known as the active mechanism that supports maintaining the wave pattern by allowing some bypass flow in the end walls to compensate for changes of speed and flow rate. An active speed control may be more preferred that allows altering the wave rotor speed to possibly maintain a preferred wave pattern. Such a control can substitute the direct coupling of the wave rotor speed to the engine speed. This can be achieved by electrical motors driving the wave rotor. However, this may require a sophisticated control algorithm that relays on measurement probes and computer processing.

The top part of Fig. 15 shows a suggested aerodynamic control of the rotational speed. Its purpose is to adapt the rotational speed to maintain a preferred wave pattern. However, it operates passively without any external control. Here special passages are introduced with outlet nozzles directed in and against the rotational direction to accelerate or decelerate the rotor, respectively. These passages can be arranged closely beside the tuned location where a compression wave is supposed to meet the end plate. If the wave pattern becomes off-tuned, the location at which the compression wave reaches the end plate moves between the inlet and the outlet of such a passage. This results in a pressure difference between the passage inlet and outlet and generates a jet that can accelerate or decelerate the rotor. If the passage is placed in rotational direction after the location where the shock wave is designed to hit the end plate, its outlet is directed against the rotational direction and the jet will decelerate the rotor, retuning the compression wave to the design location. In the same way such a passage is placed before the design arrival location of a compression wave and its outlet is directed in rotational direction which retunes the rotor by accelerating it. For a proper passive control at least one of both passage types is necessary, one accelerating and one decelerating passage.

The middle of Fig. 15 shows a reverse-flow wave rotor in which the arrival of the primary wave is tuned to the leading edge of the compressed air port. A passage with inlet just before the leading edge of the compressed fluid outlet port and an exit in rotational direction will have the primary shock wave
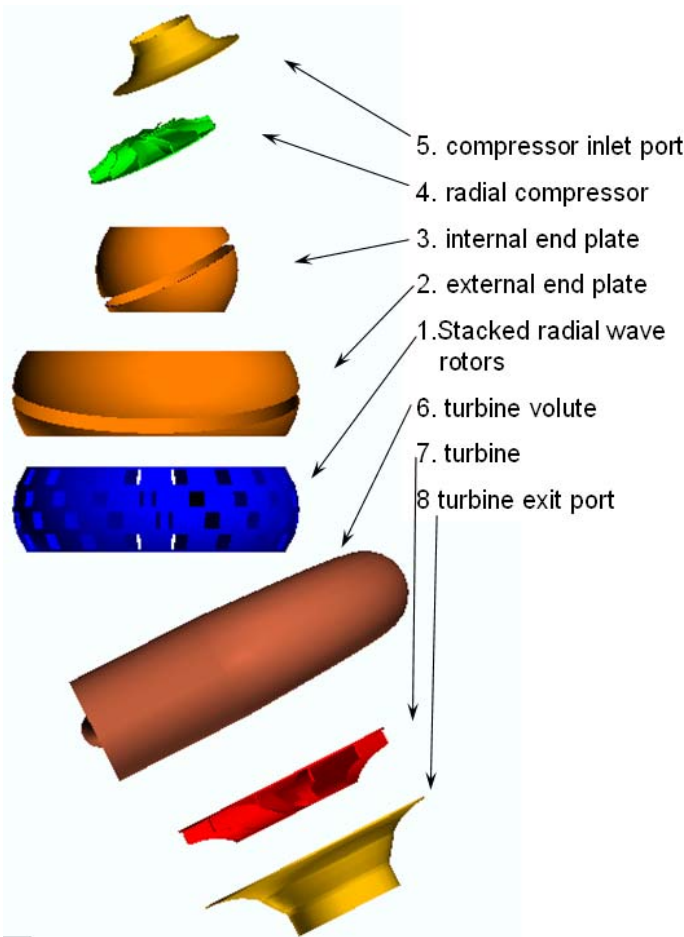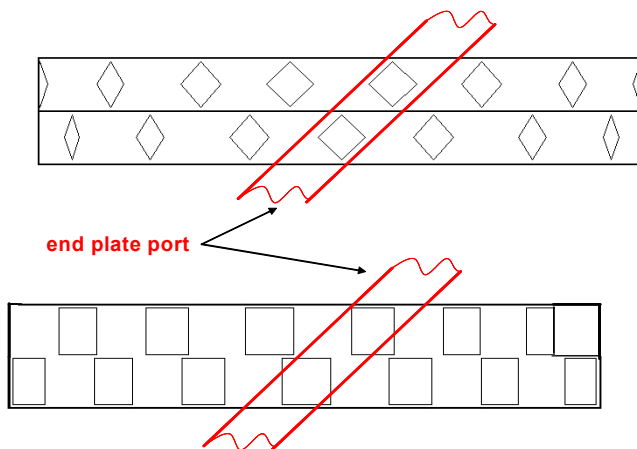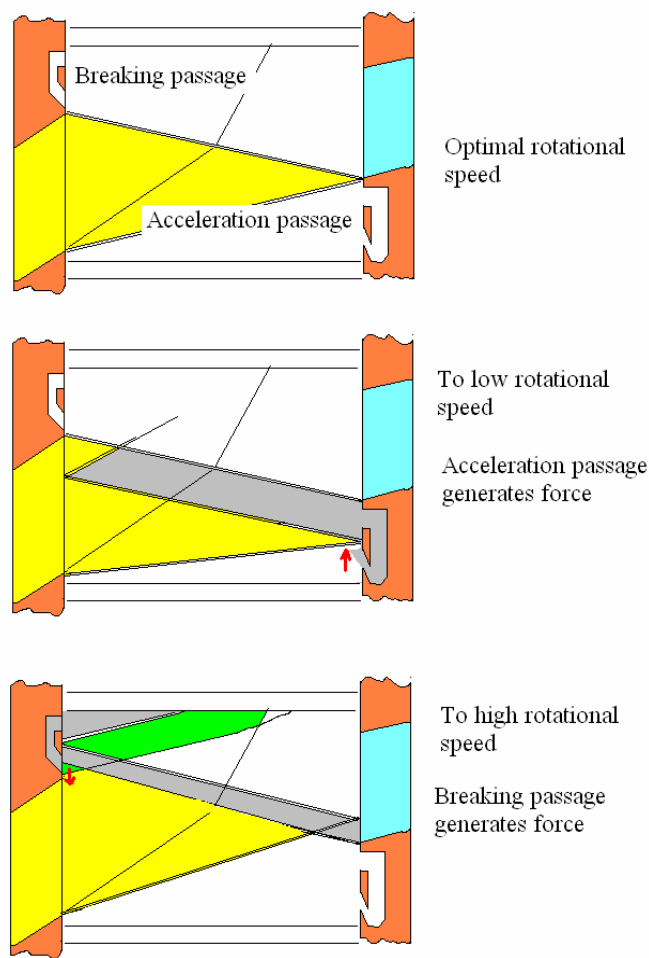
**Figure 15:** Aerodynamic control of the rotational speed

hit between both in the case of too low rotational speed. The pressure ratio across the shock wave will then induce a jet coming out of the channel exit in rotational direction and accelerates the rotor with its momentum. For deceleration the same principle is applied in the bottom part of Fig. 15 using a secondary shock wave that should arrive at the opposite end plate at the trailing edge of the high pressure inlet port. The passage outlet is directed against the rotational direction.

This principle is envisioned more for speed control rather than for a primary drive of the rotor. For the latter it is probably less effective than other driving principles including those of a self-driving rotor. However, it may allow removing all pockets, even though it may be used in combination with other active or passive control mechanisms.

## CONCLUSION

Radial wave rotor (wave disc) is an important step forward for wave rotor technology. Unlike existing axial-flow wave rotors, a radial wave rotor has radial channels where the flow enters and leaves the channels radially. Its unique features can improve the compression process, flow scavenging, and phase

separation. The manufacture process sounds easier as well. The stacked discs configuration allows a more sophisticated application for radial wave rotors, especially for gas turbine applications. Being able to embed the compressor inside the wave discs, the overall dimensions can be reduced. The active aerodynamic speed control suggested here allows maintaining a preferred wave pattern by changing the rotor rotational speed which is very beneficial in operating conditions of wave rotors.

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