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Design and Operation of Tesla Turbo machine - A state of the art review

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Abstract: Turbomachines are machines that transfer energy between a rotor and a fluid, including both turbines and compressors. While a turbine transfers energy from a fluid to a rotor, a compressor transfers energy from a rotor to a fluid. Many different designs of turbomachines are in use of which Tesla turbomachine is one, whose design is different from conventional designs. A Tesla turbomachine utilizes the viscous shear forces of a fluid (boundary layer effect) passing near a disk on an axle to transmit torque to and from the fluid. Tesla turbomachines have found wide ranging applications that include handling of mixtures of solids, liquids and gases without damaging the machine. It can be designed to efficiently pump highly viscous fluids as well as low viscous fluids. It has been used to pump fluids including ethylene glycol, fly ash, blood, rocks, live fish and many other substances. This paper attempts to present the outcomes of research carried out by various researchers during the last four decades. A summary of the modeling, simulation, and experimental procedures used to understand Tesla machines is presented. The performance of Tesla machines is found to be influenced by a number of parameters including width of disks, the number of disks, gap between disks, jet angle at inlet, inlet pressure, load applied, Mach number, Reynolds number. The paper also outlines the results of investigations performed by the researchers and further identifies the deficiencies, which can serve as a future direction to research in this field.

Keywords: *Turbomachine, viscous forces, boundary layer effect, Mach number, Reynolds number.*

1. Introduction:

Turbomachine applications have several alternatives, each of which emanates to help build the world of power. One of these ideas was put forward by Nikola Tesla, through his patent on 'The Tesla turbine' in 1913 [01], which he referred to as a bladeless turbine or friction turbine. The principle of Tesla turbine comes from two main rudiments of physics: Adhesion and Viscosity, instead of the conventional energy transfer mechanism in traditional turbines. It is referred to as a bladeless turbine because it uses the boundary layer effect and not a fluid impinging upon the blades as in a conventional turbine. The Tesla turbine is also known as the boundary layer turbine, cohesion-type turbine, and Prandtl layer turbine (after Ludwig Prandtl). If a similar set of disks and housing with an involute shape (versus circular for the turbine) are used, the device can be used as a pump. The important point of this Tesla turbine invention is that the turbine does not use friction in the conventional sense; rather it avoids it, and uses adhesion (the Coandă effect) and viscosity instead. It utilizes the boundary layer effect on the disc blades.

Tesla turbine comprises of a multiple-disk rotor contained in a housing provided with nozzles to supply high-speed moving fluid that is nearly tangential to the rotor. The fluid flows spirally inward and finally exhausts from the rotor through holes or slots in the disks near the shaft as shown in Figure 1. The fluid drags on the disk by means of viscosity and the adhesion of the surface layer of the fluid. In the process, the fluid slows down and adds energy to the disks, thereby causing the rotation of rotor before it spirals into the center exhaust. As a pump or compressor, fluid enters the rotor through holes near the shaft, flows spirally outward, and exhausts from the rotor into a diffuser as. In this configuration (when used as a pump) a motor is attached to the shaft causing rotation of the multiple-disk rotor. The fluid enters near the center, takes the energy from the disks, and then exits at the periphery.

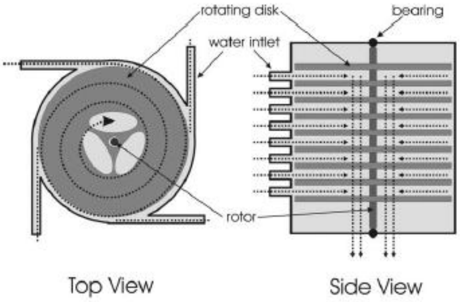


Figure 1: Tesla turbine working features [26]

After the initial focus on the new invention in the beginning of 20th century, very little research went into understanding Tesla turbines until the revival of interest in the 1950s. With the development and availability of computing facilities people started working on using simulation studies to better understand the behavior of these machines. Many attempts have been made to commercialize these machines, but have found little success mainly owing to the small overall efficiencies due to considerable losses in the nozzles when used as turbines and the diffuser or volute when used as pumps. Most designs of Tesla turbomachinery are based on intuition and simple calculations or empirical experience, and much work needs to be done in studying these losses with well defined scientific procedures in achieving optimized nozzle and diffuser designs.

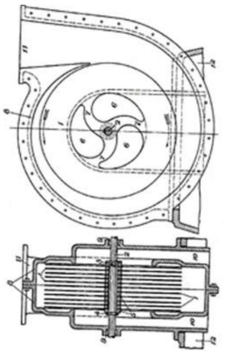
In the last few decades, interest in new designs of Tesla turbines has led to a large body of literature published in journals, conference proceedings, and other forums. Various aspects related to Tesla turbines are presented as a review in the following sections. Section 2 provides a summary of numerous patents applied and/or obtained on Tesla turbomachinery. Section 3 gives a review of the different constructional designs proposed in the literature. Various parameters influencing the performance of Tesla turbomachinery that were studied by researchers and the techniques employed in the analysis of Tesla turbomachinery are discussed in section 4. In section 5 the wide range of applications for which Tesla turbomachinery is suitable and is in use is presented. Finally we conclude the paper with section 6.

2. Patented Tesla-turbomachinery designs:

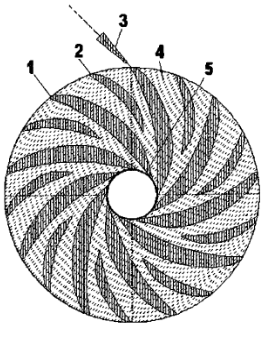
The foremost patented design of Tesla turbine by Nikola Tesla (1913) led to a great revolution in turbomachinery sector and since then, interest in new designs of Tesla turbines has led to many inventions which were patented. It is to be noted that there was little activity concerning the Tesla turbomachinery until a revival of interest began in the 1950s. This section outlines a summary of some of the notable patents on Tesla turbomachinery. There are many other patent publications available in the literature and the summary here is not exhaustive. In 1913 Nikola Tesla was granted patent for his new turbomachine invention designed for transmission and transformation of mechanical energy through fluids in an efficient, simpler, and economical manner than the conventional designs. Tesla claimed to achieve these by causing the propelled fluid to move in natural paths or stream lines of least resistance, free from constraint and disturbance such as occasioned by vanes or kindred devices, and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is receiving energy. Robert A. Oklejas and Eli Oklejas Jr [17] [21] patented their inventions which they called “gas regeneration Tesla-type turbine”. The invention claims in improving Tesla turbine efficiency by providing an apparatus that utilizes heat exchange in a Tesla-type turbine. In addition to an external regenerator, the apparatus includes a second regeneration system resulting in a compact design. In 1980 Marynowski et. al. [10], patented their invention “radially staged drag turbine”, which claims an improvement in friction turbines or drag turbines by employing a plurality of separate stages. The invention is particularly directed to applications wherein a number of stages are required to achieve high efficiency operation. In 1980 Fonda-Bonardi [07] patented the design of a “fluid injection control system” for use with Tesla-type turbines, where it is desired to control the mass flow of the fluid to the turbine without changing the fluid injection angle and without introducing turbulence. In 1983 Effenberger [03] obtained a patent for an improved vaneless fluid impeller design with variable inter-disk spacing. The disk spacing either decreases or increases with increasing radial distance from the axis of rotation depending on whether the kinematic viscosity of fluid is low or high respectively. In 2000 Joseph F. Pinkerton and David B. Clifton [22] obtained a patent on the application of Tesla turbine as a Fuel Cell or UPS (Uninterruptible Power Supply). In 2001 Entrican, Jr. [08] patented an improvement in the Tesla turbine design that utilizes the edge of the blades of the working surfaces instead of the blades face, and further utilizes both expansion blades and adhesion blades. In 2002 Guy Louis Letourneau [12] obtained a patent on the Rotor Assembly of Tesla turbine, which provides improvements to the coupling of the disc set to the rotor shaft, and spacing means of the disc members. In the same year Mark S. Vreeke and Viren H. Kapadia [19] patented an application of Tesla turbine as an alternative to power generation in miniature/micro-scale power generation systems. In the same year Danial Christopher Dial [14] received a patent that relates to the methods of facilitating the movement of fluids, transferring mechanical power to fluid mediums, as well as deriving power from moving fluids. Embodiments of the invention exploit the natural physical properties of fluids to create a more efficient means of driving fluids as well as transferring power from propelled fluids. In 2003 Scott D. O’hearen [02] took a patent on Radial turbine blade system. This invention utilizes a combination of the concepts of a smooth runner surface for working fluid frictional contact and that of blades projecting axially from plural transverse runner faces. In the same year Letourneau [12] obtained a patent which mainly relates to the inlet geometry for introducing working fluid into a turbine whose rotor is comprised of spaced apart disks. The inlet geometry directs the fluid in a manner which allows the turbine to accelerate to operating speed from standstill or from very low initial velocities. In 2005 Salvatore E. Grande and David R. Draper [03] obtained a patent on bladeless conical radial turbine wherein fluid is directed axially within the pump body to produce an axial output. The turbine has its use as pump which helps to pump water, gases, sewage, oil, multi-phase fluids, and high viscous fluids. This invention may also be adopted for use as a driver for propulsion such as naval or aerospace applications and may also be utilized as an internal combustion engine. The design has the rotor elements as conical or dome-shaped which may be venturi-shaped, convex, concave, dishshaped, which provide a smooth surface for operation utilization as a boundary layer turbine. In the same year Kenneth Hicks [11] published a patent with an objective to increase the efficiency, reliability and flexibility of continuous and/or impulse combustion turbine technology. The invention is directed to an improved method of and apparatus for a multi-stage boundary layer turbine and process cell. The inventor mainly concentrates on the design of the turbine with a technique based on the adhesion and viscosity of different mediums like gasoline, diesel, natural gas, biomass, methane, hydrogen, propane, LPG, steam, water, air, etc. The design works as a closed loop systems, which contain condenser in between the turbine and disk pack vacuum stage. He also concentrated on the disk with ceramic and catalyst coatings. In 2006 Christopher Brewer and Lavina [06] patented a conical turbine design, which is the optimized design of the traditional Tesla bladeless turbine. The design is simple and versatile, constructed from a hollow conical rotor with the base of the cone substantially sealed by an end cap. In 2007 Erich A. Wilson [13] obtained a patent on optimization in bladeless turbine. It relates to the improvement in geometric shape of an individual bracket/spacer used to build bladeless turbines, impellers, compressors, and pumps. This invention offers improvements in the bracket design to increase efficiency of energy extraction or infusion between the working mechanical components and the working fluid of the system whether the fluid is compressible, incompressible, Newtonian or non-Newtonian in nature. In 2008 Howard J. Fuller [16] in a patent that relates to wind energy, explains a turbine design which efficiently converts wind energy into mechanical power. The turbine can also be driven by fluids other than wind. The disks of the stack are held in a spaced-apart arrangement by a set of peripheral spacers, each of the peripheral spacers extending from one disk to the next. Each peripheral spacer has the shape of an airfoil. The airfoil defines a chord which extends radially inward, towards the axis of rotation of the disk. In the same year Haraldo da Silva Couto, Julio Cesar Batista [15] patented a design wherein, the smooth disks in the turbine are replaced with innovative disks called Pelton type disks. The main object of this invention is the innovative disk shape, which has the characteristics of Pelton Wheel. This Pelton type disks has a purpose to increase the torque provided by the shaft of the turbine. In 2009 John W. Detch [20] obtained a patent which relates to the field of disk turbines and more particularly to an exhaust portion of a steam-powered disk type turbine engine. It is an improved Tesla turbine design incorporating a novel structure wherein the disk stack is oriented horizontally and the hub is closed at its upper end. Vanes which are tapered such that their cross-sectional shape evolves from predominantly solid area at the top of the hub are used. In 2010 Takeo S. Saitoh [05] patented the design of a prime mover based upon a centrifugal reverse flow disk turbine. A plurality of radially engraved channel is used for transporting working fluid from entering ports, placed axially near the turbine shaft. In the same year Robert Fleming [09] patented an application of the Tesla turbine as a hybrid electric power motor system and vehicle. It is a motor vehicle which runs on the Tesla turbine as the main power source.

3. Constructional Features:

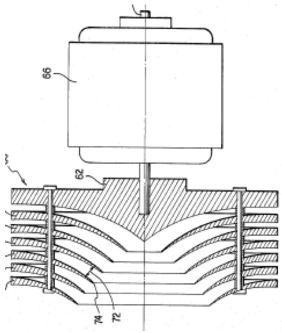
Following the original patented Tesla turbine design, several different designs of the same have been proposed and further patented. Some of the notable designs of these turbines include, the original Tesla turbine [01], Radial Turbine Blade System [02], Viscosity Impeller [03], Bladeless Conical radial Turbine [04], Centrifugal Reverse Flow Disk Turbine [05], and Hybrid Tesla-Pelton Wheel Turbine Design [15]. The salient constructional features of these designs are shown in Figure 2. It can be observed from the figures that essentially the construction of Tesla turbines consists of a rotor on which a series of disks are mounted with spacers separating each of the disks. The rotor with the disks mounted is housed in a stator with an array of nozzles fixed on the surface which are used for supplying the working fluid.



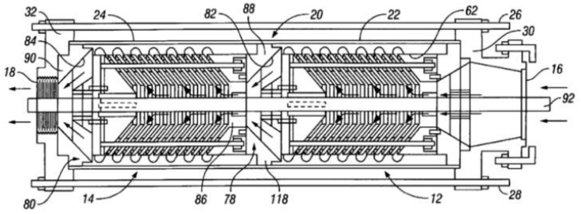
(a) The original Tesla design [01]



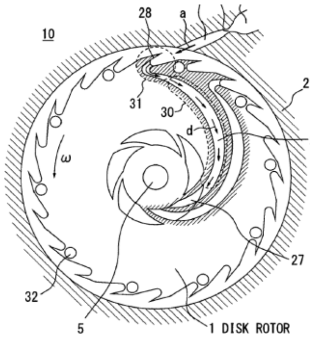
(b) Radial Turbine Blade System [02]



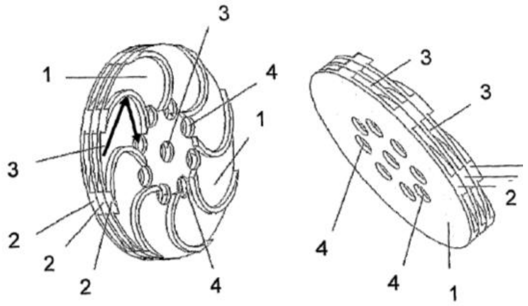
(c) Viscosity impeller design [03]



(d) Bladeless conical radial turbine [04]



(e) Centrifugal Reverse Flow Disk Turbine[05]



(f) Hybrid Tesla-Pelton Wheel turbine [15]

Figure 2: Constructional features of a few Tesla-type turbo machinery designs.

4. Performance Parameters and Design Analysis:

Since the original patented design by Tesla in 1913, while some researchers proposed modified designs to the original Tesla turbine design, some researchers showed interest on the modeling and numerical simulation studies aimed at achieving better performance of Tesla turbines. Many investigations have been carried out to determine the performance and efficiency of Tesla turbo-machinery. Most of these investigations had a certain limited application as the objective, with regard to size and speed as well as the nature of the operating fluid. However, some of the investigations have tried to establish the generalized performance of Tesla-type turbomachines. In general, it has been found that the efficiency of the rotor can be very high, at least equal to that achieved by conventional rotors. But it has proved very difficult to achieve efficient nozzles in the case of turbines, and efficient diffusers for pumps and compressors. As a result, only modest machine efficiencies have been demonstrated. Principally for these reasons the Tesla-type turbo-machinery has had little utilization. There is, however, a widespread belief that it will find applications in the future, at least in situations in which conventional turbo-machinery is not adequate.

Figure 3 illustrates a comparison of performance of conventional bladed turbines and Tesla turbines. It can be seen that the performance of one is the inverse of the other and each has a certain point beyond which a switch over between the two is sought. While Tesla turbines are found to be more efficient at smaller power output, conventional bladed designs are better when higher output power is the requirement.

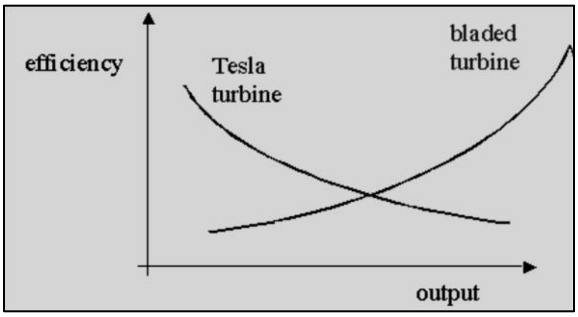


Figure 3: Graph showing the performance of Tesla turbine

The performance and efficiency of the rotor of Tesla-type turbomachinery is found to be dependent on the combination of not only parameters related to the rotor assembly, but also on the efficiency of the nozzles and the nozzle-rotor interaction. The performance of the pump is also strongly dependent on the interaction of the fluid leaving the rotor with that in the volute and on the efficiency of diffusion in the volute.

Following is a list of various parameters that were identified and investigated by researchers in arriving at better designs:

- Number of Disks
- Inner, outer radius, and thickness of the disks
- Gapsize
- Number and shape of the nozzle
- Incompressible or Non-incompressible flow
- Reynolds number
- Jet angle inlet
- Roughness of the disk
- Inlet pressure and Load applied
- Spacers geometry
- Flow medium and type of the flow
- Velocity of the flow
- Number of inlets
- Speed of the rotor
- Placement of outlet
- Type of the application
- Stator, bearing, spacer and rotor sealing's
- Radius ratio
- Dynamic and Kinematic viscosity
- Stagnation and static pressure
- Angular velocity
- Total flow rate

Apart from resorting to physical experimentation procedures, different analytical methods have been used to reveal the behaviour of Tesla-type turbomachinery, under the influence of parameters listed earlier. With the development and availability of computing facilities simulation studies are being used extensively to better understand the behaviour of these machines. In the following paragraph various design analysis methods adopted are presented.

Vedavalli G. Krishnan et. al. [31] resorted to the physical construction and experimental investigations on micro Tesla turbines at low pressure heads and reported a maximum achieved efficiency of 36% at a flow rate of 2 cc/sec with a 13 disk rotor stack. Milan Batista [32] proposed an analytical solution to the Navier Stokes equations for studying steady flow of an incompressible fluid between two parallel co-rotating disks. A combined experimental and numerical study of the transition to turbulence of rotor-stator flows in an annular cavity has been performed by Poncet et. al. [33] and a comparison of the DNS results with flow visualization is presented. Ning Wei [34] studied the significance of loss models and their applications in simulation and optimization of axial turbines. The film cooling loss method developed by author has been applied on the performance prediction of turbine, as a supplement to the loss models. Jessica Gissella et. al. [36] found that a disk with embossed airfoil impressions on its peripheral has maximum efficiency. Cros and LeGal [38] investigated the transition to turbulence of the flow confined between a stationary and a rotating disk, using visualization and video image analysis. Tim van Wageningen [39] used FEM models for calculations and optimization of a small scale hydrogen peroxide powered engine for a flapping wing mechanism micro air vehicle. Piotr Lampart et. al. [40] carried out CFD calculations on various models of Tesla turbines on the basis of the RANS model supplemented by the K-ω SST turbulence model in ANSYS Fluent. Jose Luiz Gaschem et. al. [43] solved numerically the problem of flow through a radial diffuser using the immersed boundary method with the virtual physical model for complex geometries. Peter Harwood [45] also used CFD tools in the design and analysis of Tesla turbine. S. Viazzo, S. Poncet et. al. [46] reported numerical investigations of the turbulent flow in a shrouded rotor-stator cavity by two LES codes. The first LES approach is a 3D spectral code stabilized with a spectral vanishing viscosity model, whereas the second one is a fourth order compact finite difference code associated with the dynamic subgrid model. C. J. Deschamps [48] estimated the turbulence of flow in an axial turbine model, using flow transport equations for modeling and CFD calculations using ANSYS Fluent. P. Sandilya et. al. [49] used physical modeling and experimentation and compared results obtained with those from analytical models. The differential equations used were discretized using Crank-Nicolson semi-implicit formulation. Shuichi Torii [53] investigated thermal-fluid transport phenomena in laminar flow between twin rotating parallel disks using ANSYS Fluent.

5. Applications:

Tesla's patents state that the device was intended for the use of fluids as motive agents, as distinguished from the application of the same for the propulsion or compression of fluids (though the device can be used for those purposes as well). The Tesla Turbine has not been fully utilized commercially since its invention, the main drawback in his time, was the poor knowledge of materials characteristics and behaviors at high temperatures. The best metallurgy of the day could not prevent the disks from moving and warping within acceptable limits during operation. Today, many amateur experiments in the field have been conducted using Tesla Turbines, including steam turbines (using steam produced from a burner, or even solar power) and turbos for automobiles. The application of this special turbine is not only on the normal spectrum range of turbomachines for as power plants or aero derivative turbines, its range of applications is also intended for small applications such as fluid, and material supplying pumps and blowers. It also has its applications with transfer of Low and High Viscous fluids. Following is a list of various applications envisaged by Tesla inventors, though some of which are yet to find their place in industry.

- As a turbine to generate the power comparatively nearer/equal to the conventional power generation techniques [1, 3, 4, 15].
- As higher efficient motors with low wear, friction, warping) motors [2, 9, 14, 17].
- As a pump to transfer not only liquids but also other materials like live fish, ethylene glycol, fly ash, blood, abrasive, rocks, and biomass [3, 6, 7, 10, 19, 24, 42, 44, 49].
- For power generation instead of wind vanes [15, 36]
- As impellers in the aerospace applications, nuclear power plants [3, 4, 30].
- As a Fuel Cell (miniature/micro-scale power generation systems) [18, 21].
- In hospitals for the transfer of blood, transfer of drugs at a controlled rate, etc. [3].
- As a replica for steam turbines in aircrafts. [20]
- As a pump for a high vacuum application [1, 10].
- As a UPS (Unpredictable Power Supply) [21].
- Used in the places having limitations of diffuser and collector in other type of turbines [1, 7, 25, 43].
- Efficiency is maximized, when boundary layer thickness is approximately equal to inter-disc spacing. [34,37]
- Turbines of this design can operate at temperatures above 1000°C [16, 19, 20]
- Also be used in low temperature conditions (room temperature) [35, 36, 42].
- It has only few moving parts (cheaper manufacture) and lubrication is required only for shaft bearings (environmentally friendly). [2,6,31]
- There is no loss of the inlet fluid which can be collected at the center of the rotor [1, 5].
- In conventional pumps, fans, compressors, generators, circulators, blowers, turbines, transmissions, various hydraulic and pneumatic systems [1, 9, 13, 14].
- Used in naval applications [3].
- To produce a required pressure differential [2, 5].
- As a centrifugal turbine (centrifugal reverse flow turbine) [4, 14].
- For desalinization of water and hydrogen generation [10].
- In self-starting applications [11].
- Transferring compressible, incompressible, Newtonian and non-Newtonian fluids [8, 12].
- In the fields having limitations of vibrations in the turbine [17].
- In the micro fabrication techniques to construct micro electro mechanical systems (MEMS) [18, 34].
- To produce high vacuum [23, 40].
- To derive motive power from steam [23].
- To achieve high rotational speeds even twice to the conventional turbine [7, 23, 31].
- As a Valvular Conduit [24].
- As ultra-small profile heat engines [26].
- In low pressure head flow [26].
- Used to eliminate unsteady, windage, partial admission, lacing wires and exhaust losses [29].
- As a subsonic flow turbine [29].
- Power supply for mobile robots [34].
- In inkjet, printers, and fuel injectors [34].
- In problems involving fluid-structure interaction [38].
- It can be used in Pico hydro applications. [46]

6. Conclusions:

It is worth mentioning that the Tesla turbomachinery as a turbine, compressor, and pump specially fits into those instances where compacted unities are required for generating electrical power or transferring materials or pumping fluids are required as in the case of isolated areas. It should be noticed that, as a unique source of rotating motion of this type, Tesla machines can run under a very wide spectrum of not only fuels but also fluids in general.

Tesla-type turbomachinery probably cannot prove competitive in an application in which more conventional machines have adequate efficiency and performance. Thus, it cannot be expected to displace conventional water pumps or conventional water turbines or gas turbines. Tesla-type turbomachinery can be considered as source of standard in applications in which conventional machines are inadequate. This includes applications for small shaft power, or the use of very viscous fluid or non-Newtonian fluids. It is an advantage that multiple-disk turbomachines can operate with abrasive two-phase flow mixtures with less erosion of material from the rotor.

In general, it has been found that the efficiency of the rotor can be very high, at least equal to that achieved by conventional rotors. But it has proved very difficult to achieve efficient nozzles in the case of turbines, and efficient diffusion for pumps and compressors. As a result, only modest machine efficiencies have been demonstrated. Principally for these reasons the Tesla-type turbo-machinery has had little utilization. There is, however, a widespread belief that it will find applications in the future, at least in situations in which conventional turbo-machinery is not adequate.

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