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DESIGN AND ANALYSIS OF THREE ROTOR ROTARY ENGINE

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ABSTRACT

This paper is an outcome of design and analysis of a 3 rotor rotary engine. Unlike conventional reciprocating engines the rotary engines perform more efficient in terms of high speed and tongue generation. In this paper the design aspects of the rotary engine are carried out and the emphasis is made for the design features and evaluation of strength and mechanical properties for with different materials such as Zirconium, Aluminium silicon carbide and Aluminium alloys. At the end of the report the material Zirconium is suggested for adopting in the rotary engine. And the other materials used for this engine have shown less effect as in comparison. Further there is a lot of scope available to improve the performance of the engine.

Keywords: Design And Analysis, Three Rotor Rotary Engine, Material Investigation.

I. INTRODUCTION

Rotary engine is first visualized and found by Felix Wankel he may be treated as a father of rotary engines. One dream has made his life to invent this rotary engine. This work is about the development of an advanced engine that fulfils the gap between our fiction and reality in terms of transmission of the energy and power. Rotary engine is an engine of this type. In this project the complete analysis about the rotary engine has been done for the betterment of its performance. At the end some suggestions have been made to develop an engine of this type.

The engine is modelled and designed in such a way that it can develop doesn't violate the second laws of thermodynamics [1]. That is "without any external aid or agency of forces or power an engine cannot transfer the energy from low temperature reservoir (sink) to high temperature reservoir (source), and also 100% of the energy conversion is not possible". The rotary engines is an energy conversion machine, consists of rotary motion unlike the other engines have the reciprocatory motion. In addition to this some of the other benefits offered by the rotary engines initiated to carry out this work [2]. All these parameters were discussed in the subsequent chapters. In the next chapter the literature survey has been made for the better understanding and also for finding the optimal result. This survey is very much useful in the analysis of the engine from part to part. This has made the engine to get modelled in a very meticulous manner and also for the analysis of it. Next a detailed methodology has been developed for complete process of modelling and analysis [3]. It includes a flow chart that can make a clear vision of know-how about the project.

After this the design considerations were made in order to get a plan for a perfect outcome and also to find the key parameters and variables that influence the performance and erection of the rotary engine. Unlike the commonly used rotary engine, this work contains a three rotor rotary engine [4]. That means the engine do contains three rotors and three stators for the geometry [5]. And in addition to this a common shaft has connected among these chambers to get the power accumulated in a single shaft. Otherwise it would incur extra losses.

Each engine cylinder is comprised of three chambers one is for the compression and the other is for the power stroke and the last one is exhaust. But as in the case of the reciprocating engine strokes are clearly visible, here in this rotary engine these strokes / chambers are get interfered one with other as the driving mechanism is rotary motion [6]. Hence a circular motion will be generated within the chamber for the rotor. Each engine has one rotor and one stator that is outer shell or casing.

In addition to this the cylinder used in this engine not like a single cylinder but like a combination of the two cylinders, which are coinciding one with the other. And this type of set up is made three types such that a common shaft is connected among these three cylindrical chambers axially so that a uniform torque will be generated. This set up is illustrated in the subsequent chapters clearly [7].

II. LITERATURE SURVEY

This section includes the data and a record of information that is gathered from the various sources around the globe in order to understand well about the rotary engine. Rotary Engine is a type of engine in which the motion of the engine is rotary. That is a circular motion. In general all the engines are having the reciprocatory motion but this rotary engine is a kind of special engine intended to used for high power generation particularly for the sake of may be sports cars or racing automobiles. The rate of combustion in this rotary engine is high enough in order to generate greater thrust with less mileage [8]. The fuel air ratio used in this engines is also more when compare with the conventional internal combustion engine. Wankel engine is one of the examples for the rotaty engine this was developed from so many numbers of experiments in 1960's by a German Engineer Felix Wankel.

Rotary engines have multiple combustion chambers that implies greater rate of combustion efficiency. The firing order is mostly alternate numbers such as 1-3-5-7-2-4-6 in the case of seven cylinder rotary engine. The sun and planetary gear drive is mostly used in this engines with more in number of gear ratio for the conversion of the speed. Engines of these types can produce a horse power of 255 to 6500 and torque ranges from 200N-m to 5000N-m. The following specifications are generally maintained for most of the rotary engines for better efficacy. Bath tub type of combustion chamber is used with a compression ratio of 9:1 [9]. And air induction is done by using the 4-port induction. And one important parameter to be considered is cooling of the engine. This is done by means of water and engine oil. It's a two way cooling system. The idle speed of the engine usvally will be 700 to 750 r.p.m. the engines are equipped with the petrol tank capacity of 70 to 80 litre. The displacement would be about 1000cc. And the maximum speed ranges from 8500r.p.m to 9000r.p.m. The specifications and the concept used to make these engines might changes like adiabatic conditions within the engine cylinder without compromising the material properties [10].

So many research works have yielded results in improvement of the engine. And it's a continuous phenomenon in the betterment of the existing model. As per the research paper Study of Virtual Design and simulation of Rotary Engine Based on Pro/E written by Wnag Jinlong. "Rotary engine is used for the reduction of the emissions particularly the Cox, NOx. The modifications in this regard have made significant outcomes such as low input, low noise, low cost too."

From the thesis of Michael Irvin Resor "Computational investigation of rotary engine homogeneous charge compression ignition feasibility". This work resulted the following: a computational fluid dynamics model is made for the improvement of ignition system made by Homogeneous Charge Compression this is a better option for the improvement of the efficiency [11].

From the thesis of Sarah Elizabeth Warren "New Rotary Engine Designs by Deviation Function Method" it is suggested that multiple design profiles were made for the flexible design consideration and their applications. Some of the developed models were made in process development and their illustrations. Some of the features of this method is arc based and non arc based for the contour shapes of the engine cylinders. This has made better results.

From the research paper of K.M. Jagdale & Prof. V.R. Gambire "Low Pressure High Torque Quasi Turbine Rotary Air Engine" it is found that a Quazi turbine is made for the utilization to the rotary engine that works absolutely at low pressures and also low r.p.m. and then it has also recovers the waste energy that was either developed within the engine or may be form outside too.

From the research paper of D.C. Wlther and A.P. Pisano tiltled "mems rotary engine power system: project overview and recent research results". the fuels used in the rotary engines are taken in to investigation to improve the available part of the energy by making it as extraordinary high in specific density of the Hydrocarbons so that it can boost up the energy dissipated up to 20times. It has enhanced the reduced emissions too by a providing a better combustion within the chamber of cylinder [12].

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III. METHODOLOGY

Methodology is about the method that we use to understand, analyze and finalize the data and details about the rotary engine. This section contains the self made flow chart about the steps and the sequence of operations to be carried out [13].

The above flow chart is a self explanatory diagram that depicts the various branches under the roof of rotary engine. The first step in making this rotary engine is the selection of parameters that are needed for the design and analysis such as the stress, strain both mechanical and thermal and then the efficiency of the engine along with the power that is going to get developed along with the parameters such as speed, torque and related [14]. Simultaneously the selection of the material that is required for the various components of the engine and its parts. As this engine would produce more amount of energy and at the same time it also dissipates more amount of heat as compare with the conventional engines [15]. Hence the materials used for this engine would differ from the others in the way desired. Generally materials are classified as hot materials and cold materials. These two categories serves the purpose and discussed clearly in the subsequent sections.

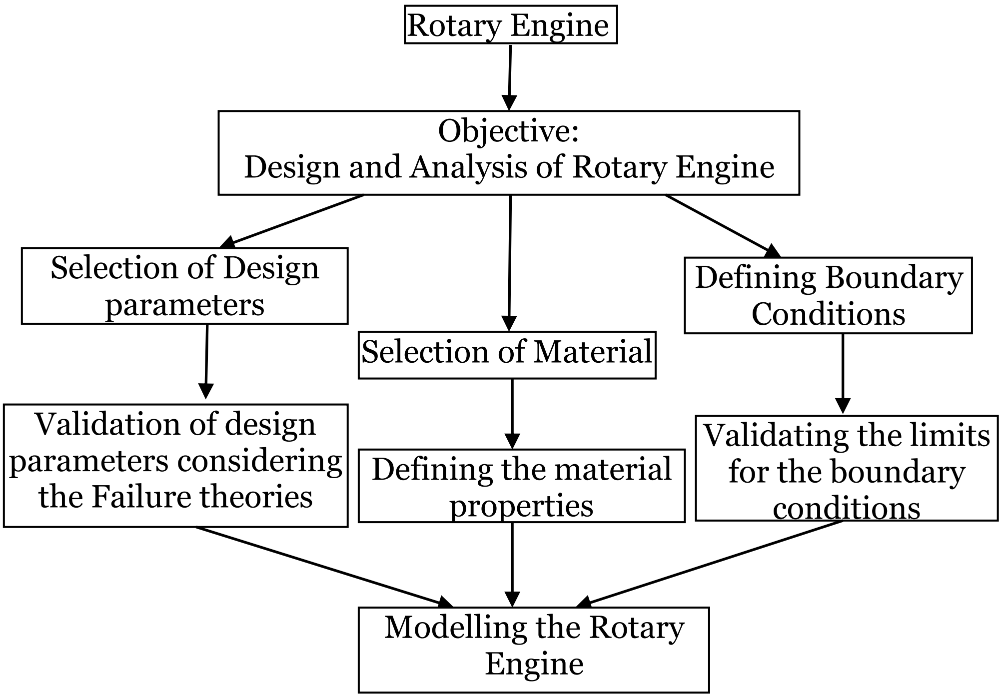

Figure 1: Flow chart of designing of rotary engine

Defining the boundary conditions is another task needs to be taken into consideration for knowing the limiting values and the interval for the parameters. These are very essential for the designing of any kind of the element particularly in the cases of engines and machines. The boundary conditions for various parameters have been defined by the collection of so much of data of the experiments conducted from the ages this concept has been developed. For a particular parameter say may be for a specified capacity of the engine the speed in r.p.m may vary by an amount.

Then the validation of the design parameters according the types of theories of failures was considered. It is assessed on the materials we opt for the engine. Generally all the materials does not lie in the same category of the unique failure theory. So the ductile and brittle materials will be assessed accordingly [16].

The defining of the material properties is one more important aspect for the calculation of the engine strength and related. One important point to be noted here is that outer surface of the engine would be coated with the adiabatic materials for the sake of retaining the energy that was developed after the ignition. A coating of the High Strength Temperature Resistant HSTR alloys were used for this purpose in order to ascertain the energy that is generated. At the same time the outer surface of the coating will be coated with the materials of higher

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thermal conductivity to transfer the heat that is generated in the engine. This is an important parameter to protect the engine and also it promotes hike in the durability and sustainability of the engine.

By combing all these parameters a basement is created for the modelling and designing of the engine.

IV. DESIGN CONSIDERATIONS

As this project is about the designing of the three rotor rotary engine

Table 1: Formulae for the rotary engine geometry

Displacement	$V_s = (3\sqrt{3})\,Rwe$
Theoretical compression ratio	$\epsilon_{th} = 1 + (((9\sqrt{3})eR)/(e^2\,\Pi + eR\,(8\cos\Phi - 3\sqrt{3}) + \Phi((2R^2/3)+12e^2)$ where $\sin\Phi = (3e/R)$
Maximum tip velocity	u_{max}: $((2\Pi n_E((R/3)+e))/1000)$ where n_E : output shaft speed (rev/s)

Table 2: Specifications of the engine with numerical values

Turning Level			265 PS
Type			Gasoline, Rotary Piston
Total displacement			0.654x3
Number of cylinder			Inline 3 rotor Longitudinally mounted
Bore x Stroke			240.0mm x 180.0mm x 80.0mm
Compression ratio			9.0:1
Maximum output	HP / rpm		260 / 6,500
Maximum Torque	kg-m/rpm		30.0/5,000
Port Timing	Intake	Opening	Primary – 45° Secondary – 32° Tertiary – 16°
		Closing	Primary – 50 Secondary – 50 Tertiary – 50
	Exhaust	Opening	75°
		Closing	48°
Idle speed	rpm		700
Lubrication system	Type		Forced supply
	Oil pump		Trochoid type
	Oil cooler		Water cooled, Electric powered
Cooling system	Type		Water-cooled, Electric powered
	Radiator		Sealed type
Super charger type			Turbo
Intercooler type			Air-cooled
Air purifier	Type		Paper filters
	Number		1
Fuel pump			Electric
Fuel injection			Electronic
Jet nozzle	Type		Pintle-type
	Nozzle	Number	1

		Diameter mm	1.31(primary) 2.34(secondary) 3.32 (tertiary)
	Injection pressure kg/cm^3		2.55

The rotary engine supposed to be made with the three rotors and for that the above said numerical will be opted for the best outcome and results. The above values have been extracted from the various research findings and outputs. The fuel used in this engine would be gasoline. And the octane number for this fuel would be around 87 for a normal quality and it will be about 88-90 for the mid grade fuel and it is 91-94 for the premium quality fuel and here the fuel may be used is premium quality and a combination of mid grade too. Hence the tendency of knocking will be greatly reduced.

The displacement of the engine along with the bore and stroke values have been given in the table. The compression ratio for this engine would be 9:1 and this engine will have a high amount of volumetric efficiency. Coming to the speed of the engine that is going to get generated is about 5000 o 7000 r.p.m and the maximum limiting speeds in the rotary engine series would be about 18000 to 20000 r.p.m. too. The maximum permissible power is estimated to develop is 260HP at the range of speed in between 6000 to 7000r.p.m. and in addition, the maximum torque generated is 30 kg-m. At an estimated speed of 4800 r.p.m. to 5500 r.p.m.

For the combustion chamber the port opening and closing will as follows. The opening for the first engine would be at $45^{o}$and the second engine opening will be at an angle of 32^{o} and for the third engine it would be 16^{o} prior to the rotation of the crank shaft. Likewise the closing will be at an angle of 50^{o} of the crank shaft for almost all the engines. The idle speed of the engine would be about 700 r.p.m. approximately.

The lubrication requirement is another important consideration for the engine to work properly. Here this engine would use a forced type of lubrication and the oil pump is of trochoid type. Along with this the cooling facility will be provided with electric powered and water cooled. On air purifier will be set up for the supply of dirt free air.

Table 3: Differences between Single and three rotor rotary engine

S no	Parameter	Single rotor rotary engine	Three rotor rotary engine
1	Number of rotors	1 (single)	3 (three)
2	Power output	Less	More
3	Speed	Less	More
4	Torque	Less	More
5	Construction	Simple	Complex
6	Emissions	Less	More
7	Weight	Less	More
8	Strength	Less	More

4.1 Drawings

The drawings of the part and full view of the engines were shown below. These drawings will be of self explanatory nature.

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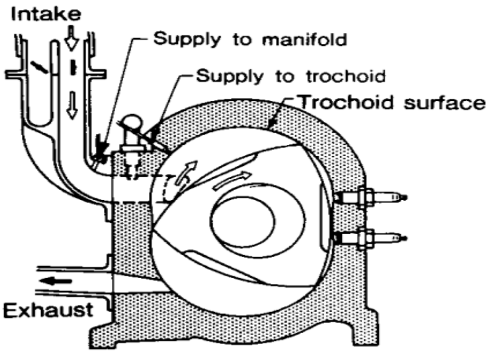

Fig 2: Schematic view of Rotary Engine

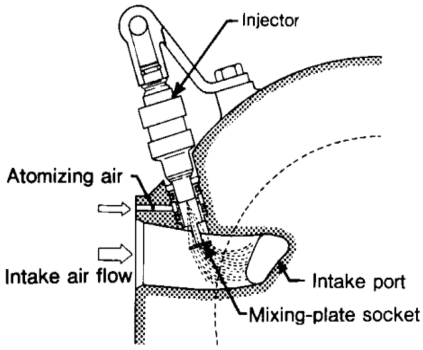

Fig 3: Fuel injector with mixing setup

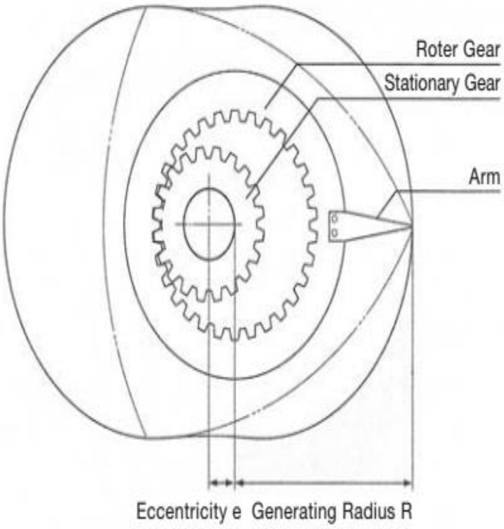

Fig 4: Peritrochoid curve

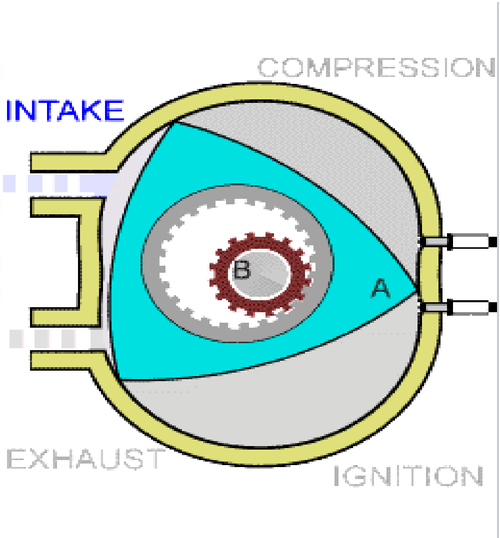

Fig 5: Rotary engine sectional view

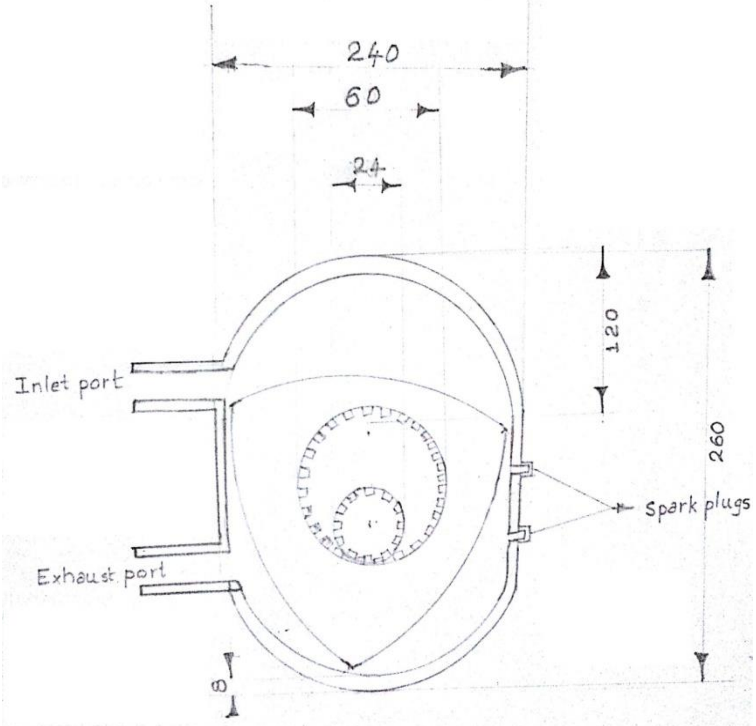

Fig 6: 2D view of 3 rotor rotary engine

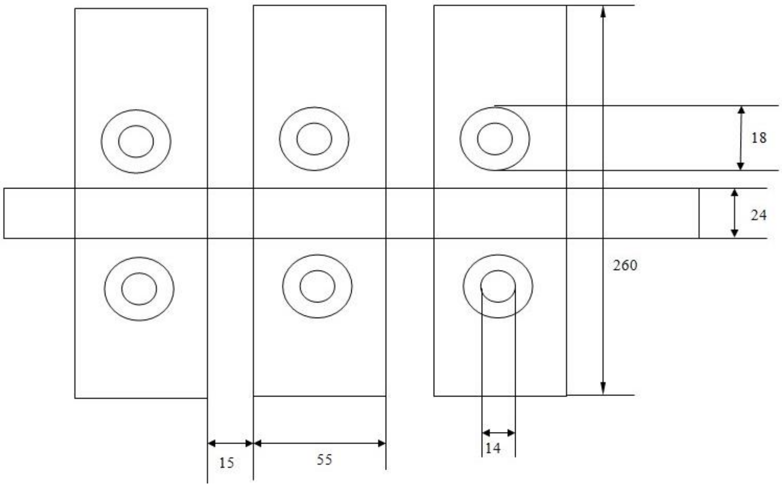

Fig 7: 3 rotor sectional view

4.2 Material Selection

The selection of the material will be made according to the purpose it suppose to serve. Here the main consideration is about the ability and capability of the material to sustain the temperature and pressures along with the stresses generated within the engine. Mainly the HSTR alloys were used to serve the purpose for the fulfilment of the objective. And in addition to this the processing of the metals or alloys is an important consideration in attaining the results desired. Mainly the materials used to in this engine would of two types they are Hot materials and the other would be Cold materials. This classification is generally made based on the Recrystallization temperature. As such some of the materials will be selected and they were processed to find their derived properties which may serve the purpose to the extent desired. This is illustrated in the following flow chart and also the table.

Table 4: Materials used for rotary engine

S no	Part name	Material
1	Spark plug	High Nickel alloys, Aluminium oxide ceramic, steel wire
2	Engine cylinder	Zirconium
3	Cylinder inner walls	Adiabatic lining
4	Cylinder outer coating	Higher thermal conductive material
5	Rotor	HSS
6	Trochoid gear	HSS

4.3 Boundary Conditions

Boundary conditions are the values that are required in the designing and fabrication of the rotary engine. Various boundary conditions of the parameters used in the design of the rotary engine is illustrated in the below table. Every parameter must be tangible in order to design it effectively and efficiently. Otherwise even at the time of fabrication too the values will vary, that is very common thing in the machine. But at the same time three must be tolerance limit must be set in order to avoid the problem that may cause a severe damage to the engine. In this context the following table also describe the properties along with the tolerance limit in order to protect the engine. These boundary conditions are very essential in the performing the operations and also to find the further stresses and also the fatigue related parameters. And in addition to this the vibrations and also the damping parameters also will be taken in to consideration.

Table 5: Boundary conditions for the parameters used in rotary engine

S no	Parameter	Boundary values
1	Speed r.p.m.	4500 to 6500
2	Power	245 to 263 HP
3	Thickness of cylinder	50mm
4	Diameter of rotor shaft	240mm
5	Teeth on sun rotor	32
6	Teeth on planet rotor	16

V. DESIGN CALCULATIONS

The calculations in the design are basically of two types they are topological (geometrical) and the other is about the physical design such as factor of safety. Here both the types of designs were done. Generally the topological designs come under the modelling part of the engine, which is done by manual design and with the help of the modelling software such as AutoCAD. And the physical design do confines the stresses, strains, fatigue, vibrations, damping and such dynamic design parameters generally done by manually and also with the commercial software's such as ANSYS. Here the topological designs were taken with an emphasis to justify the objective. And some of the important parameters of physical designs also considered. A detailed drawing so the rotary engine was made to the extent needed. Total three materials were taken into consideration for the assessment of the materials needs to be opted for the engine. They are Zirconium, Aluminium silicon carbine and Aluminium alloy. Each of these are unique in characteristics yet as a whole without contradicting the objective zirconium is suggested.

VI. RESULTS

The three materials were given under and their comparison too. From these tables it is evident that stresses and along with that the strains do found.

Table 6: Properties of Zirconium

Density			5.7 g cm^{-3}	
Thermal conductivity			3e-002 W cm^{-1} C^{-1}	
Specific heat			9e+006 erg $g^{-1}C^{-1}$	
Temperature C	Young's modulus dyne cm^{-2}	Poisson's ratio	Bulk modulus dyne cm^{-2}	Shear modulus Dyne cm^{-2}
900	1.8e+012	0.3	1.5e+012	6.9231e+011

Pressure 1.2666e+006 dyne/cm^2 and the temperature is = 450^{o}C

The above table depicts the various properties of the Zirconium all these values have been extracted from the various sources as listed in the bibliography. As this report is an investigation of possibilities and the opportunities for the design of rotary engine. The optimum conditions have been derived for the further development and deployment.

Table 7: Results of investigations for Zirconium

Object name	Total deformation	Total Velocity	Equivalent Elastic strain	Equivalent stress	Equivalent elastic strain
Minimum	3.8198e-002 cm	7.5765e-002 cm/s	1.5477e-008 cm/cm	16589 dyne/cm^2	1.0746e-005 cm/cm
maximum	4.1794e-002 cm	8.2897e-002 cm/s	3.5288e-005 cm/cm	5.1388e+007 dyne/cm^2	1.4217e-005 cm/cm

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From the analysis and the investigations the maximum and minimum deformations along with the total velocity, equivalent elastic strain, equivalent stress and equivalent elastic strain have been found.

Table 8: Properties of Aluminium silicon carbide

Density			2.81 g cm^{-3}	
Temperature C	Young's modulus dyne cm^{-2}	Poisson's ratio	Bulk modulus dyne cm^{-2}	Shear modulus Dyne cm^{-2}
900	1.5e+012	0.3	1.25e+012	5.7692e+011

The above table shows the properties of the Aluminium silicon carbide, this material is do considered for the usage as a substitute for the rotary engine. However it may be used but with a compromise in the usage limitations.

Table 9: Results of investigations for Aluminium silicon carbide

Object name	Total deformation	Total Velocity	Equivalent Elastic strain	Shear Elastic strain	Equivalent elastic strain
Minimum	7.5423e-002 cm	0.1496 cm/s	1.3352e-008 cm/cm	1.1356e-008 cm/cm	1.3352e-008 cm/cm
maximum	7.7532e-002 cm	0.15378 cm/s	3.7744e-005 cm/cm	1.5042e-005 cm/cm	3.7744e-005 cm/cm

This table enlists the results of the aluminium silicon carbide have the maximum and minimum values of the total deformation, total velocity, equivalent elastic strain, shear elastic strain and equivalent elastic strain.

Table10: Properties of Aluminium Alloy

Density	2.77 g cm^{-3}
Coefficient of Thermal expansion	2.3e-005C^{-1}
Specific heat	8.75e+006 erg g^{-1}C^{-1}
Compressive yield strength dyne cm^{-2}	2.8e+009
Tensile Yield strength dyne cm^{-2}	2.8e+009
Tensile Ultimate Strength dyne cm^{-2}	3.1e+009

The above table shows the properties of the material Aluminium alloy, to use as an alternative for the rotary engine.

Table 11: Results of investigations for Aluminium Alloy

Object name	Total deformation	Total Velocity	Equivalent Elastic strain	Shear Elastic strain	Equivalent total strain
Minimum	0.12153	0.239 cm/s	2.3346e-005 cm/cm	6.197e-003 cm/cm	2.3347e-005 cm/cm
maximum	0.19465	0.386 cm/s	1.8762e-002 cm/cm	5.8001e-003 cm/cm	1.8763e-002 cm/cm

This table enlists the results of the aluminium alloy have the maximum and minimum values of the total deformation, total velocity, equivalent elastic strain, shear elastic strain and equivalent elastic strain.

VII. CONCLUSION

The designing of the rotary engine along with the fundamentals about the rotary engines have been explained. And also the steps and sequence to be followed for the designing of the rotary engine have been described. This work has made an effort in the path of the making of a rotary engine. In continuation with the above said data there may be some kind of modifications or editing's required for the betterment of the engine in the coming course of time. As change is inevitable. The hike in productivity along with the improvement in the output is essential for the machine. Mainly the generation of the thermal energy and conversion of it in an effective manner is essential. At the end of the report the material Zirconium may be adopted for the rotary engine. And the other materials used for this engine have been enlisted in the report. There may be some modifications made in order to improve the performance of the engine furthermore.

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