Kinematics of Crankshaft for 2C Turbo Mazda Jeep Engine

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Abstract -- An engine is a device, which transforms one form of energy into another form. A crankshaft is one of the parts of an engine. It receives power from the pistons and connecting rods and transmits power to the flywheel and clutch. And it also converts reciprocating motion of piston into rotary motion. The crankshaft is subjected to shock and fatigue loads. The separate processes occurring in engine are considered and calculated with a view to determine the expected parameters of the cycle, the engine power and performance and the pressure of the gases in the space above the piston depending on the angle of crank travel. The basic dimensions of an engine, cylinder diameter, stroke of piston, diameter and length of main journal, diameter and length of crank pin, distance between two adjacent cylinders, the width and thickness of crank cheek, radius of fillet between cheek and main journal, and radius of fillet between cheek and crank pin are calculated from the expected parameters of the cycle. Masses of reciprocating part, connecting rod and crank are also calculated to determine the centrifugal forces. The forces of gas pressure in the cylinder, the forces of inertia of the moving parts in the mechanism and the friction forces are also calculated to find the transmitted force, normal force, and force along the connecting rod. Torque transferred via the crankshaft to the flywheel and transmission system, and tilting moments are also determined from the net force.

Indexed Terms: crank web, crank pin, inertia, main journal, tilting moments

I. INTRODUCTION

Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston to a rotary motion with a four link mechanism. Since the crankshaft experiences a large number of load cycles during its service life, fatigue performance and durability of this component has to be considered in the design process. Design developments have always been an important issue in the crankshaft production industry, in order to manufacture a less expensive component with the minimum weight possible and proper fatigue strength and other functional requirements. These improvements result in lighter and smaller engines with better fuel efficiency and higher power output. The main function of the crankshaft is to change rotary motion of piston to rotary motion. The connecting rod is connected to the piston pin and to the crankshaft by the crank pin. The output end of the crankshaft has flywheel. The front end has the gear or sprocket that drives the camshaft, the vibration damper and the drive-belt pulley.

The types of crankshaft depend upon the engine construction and engine design (V-type, inline, vertical, horizontal and rotary). Generally, the crankshaft which depends upon the position of the crank can be divided into two types, side-crankshaft and center-crankshaft. The crankshaft which depends upon the number of the crank in the shaft may also be classified as single-throw or multi-throw crankshaft. A crankshaft with only one side-crank or center-crank is called a single-throw crankshaft whereas the crankshaft with two side-cranks, one on each end or with two or more center-cranks is called multi-throw crankshaft. In general, automotive vehicles are both spark-ignition (petrol and compresses natural gas) engine and compression ignition (diesel) engine. The cooling system of engine is liquid cooled system used by centrifugal pump and driven by crankshaft with V-belt. The accumulating pump for fuel metering system is vacuum type. The system is operated mechanically and driven by eccentric lobe on the camshaft. The type of spark-ignition is battery ignition system. The lubricating oil pump is rotor type and is driven by camshaft. Full-flow oil filter is used to filter circulating oil. The structure of valve train is overhead valve system. Each cylinder has one intake valve and one exhaust valve. The type of tappet and its surface is flat face. The rocker arm is an integral type, not a two-piece type. Camshaft is driven by timing gear from crankshaft pinion [1].

The crankshaft, connecting rod, and piston constitute a four bar slider-crank mechanism, which converts the sliding motion of the piston (slider in the mechanism) to a rotary motion. Since the rotation output is more practical and applicable for input to other devices. The concept design of an engine is that the output would be rotation. In addition, the linear displacement of an engine is not smooth, as the displacement is caused by the combustion of gas in the combustion chamber. Therefore, the displacement has sudden shocks and using this input for another device may cause damage to it. The concept of using crankshaft is to change these sudden displacements to a smooth rotary output, which is the input to many devices such as generators, pumps, and compressors. It should also be mentioned that the use of a flywheel helps in smoothing the shocks [2].

II. DESIGN CALCULATIONS

Technical specifications of 2C Turbo Mazda Jeep engine are as follows.

Bore, D = 86 mm

Stroke,L = 94 mm

Displacement volume = 2184 cm^3

The rated power, BHP = 85hp

The crankshaft speed, n = 4500 rpm

The number of cylinder, i = 4

The compression ratio, r = 23

The temperature increment, ΔT= 30˙C

The temperature of residual gases, T_{res} = 800 K

Ambient pressure, P_0 = 1 atm =105 N/m^2

Ambient temperature, T_0 = 293 K

Characteristic gas constant, R = 287 J/kg K

1. Calculation of Engine Parameters:

The separate processes occurring in an engine are considered and calculated with a view to determine the expected parameters of the cycle, the engine power and performance and the pressure of the gases in the space above the piston depending on the angle of travel. Parameters obtained from the thermal calculation of engine are described in TABLE I.

Table 1: Calculated Results of Engine Parameters

Parameters	Pressure (MN/m^2)	Temperature (K)
Residual gas	0.18	800
Admission	0.135	324
Compression	8.506	998
Combustion	15.311	2343
Expansion	0.388	1029

2. Construction of Indicator Diagram:

Choose the scale of indicator diagram in order to get the height of diagram, approximately 1.2 to 1.5 times the base of diagram. On the volume line, make a piece of line which is equal to piston stroke S. Then, the value corresponding to combustion chamber is determined by

$$V_c = OA = \frac{AB}{r-1} \quad (1)$$

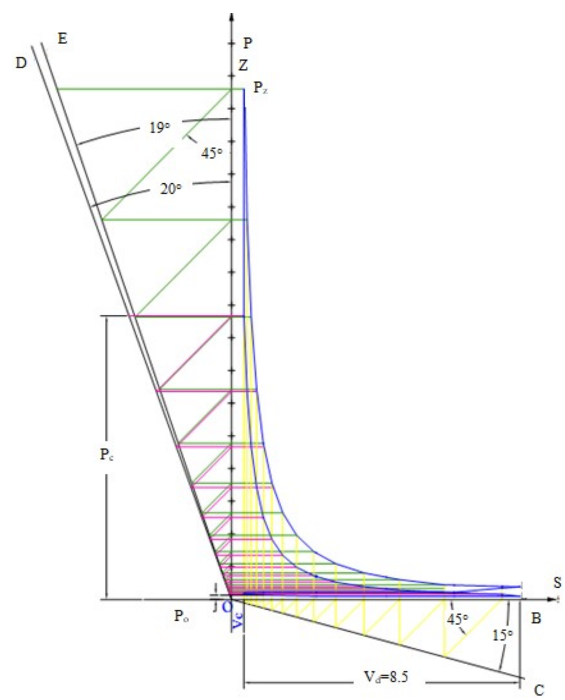

Fig. 1: Developed Indicator Diagram

Draw the polytrophic compression and expansion lines by the graphical method from the beginning point O. The piston stroke can be calculated by the formula,

$$S=\left[(1-\cos\phi)+\frac{\lambda}{4}(1-\cos 2\phi)\right] \quad (2)$$

Since the velocity is the rate of change of displacement with respect to time. Therefore, the piston velocity 'v' can be calculated as follow.

$$v = R\omega\left[\sin\phi+\frac{\lambda}{2}\sin 2\phi\right] \quad (3)$$

The acceleration 'a' is taken from the time derivative of the piston velocity.

$$a = R\omega^2\left[\cos\phi+\lambda\cos 2\phi\right] \quad (4)$$

3. Calculation of Forces Acting on the Crankshaft:

The forces in a crank gear are divided into the forces of inertia of the moving parts in the mechanism and the friction forces. And gas pressure of any crank angle can be determined from an indicator diagram plotted on the basis of thermal calculations. The results from MATLAB program are described in TABLE II, III and IV.

The force of the gas pressure can be calculated by

$$F_G = (P_g - P_0)\, A_p \quad (5)$$

The mass of connecting rod (i.e, to the piston pin axis),

$$m_{rod.pp} = 0.25 \times m_{rod} \quad (6)$$

And the mass of connecting rod (i.e, to the crank axis),

$$m_{rod.cr} = 0.75 \times m_{rod} \quad (7)$$

The reciprocating mass,

$$m_i = m_p + m_{rod.cr} \quad (8)$$

The inertia force,

$$F_i = (-)\, m_i\, R\, \omega^2 (\cos\phi + \lambda \cos 2\phi) \quad (9)$$

The piston side thrust against the cylinder wall,

$$Q = F\lambda \sin\phi \quad (10)$$

Assume, the ratio between the crank radius and the connecting rod length,

$$\lambda = \left(\frac{1}{4.2}-\frac{1}{3.2}\right) = 0.28$$

The tangential force to the crank radius circle,

$$F_t = K\sin(\phi+\beta) \quad (11)$$

The normal force directed along the crank radius,

$$N = \frac{F}{\cos\beta} \times \cos(\phi+\beta) \quad (12)$$

The force directed along the connecting rod axis,

$$K = F \times \frac{1}{\cos\beta} = F \times \left[1+\frac{\lambda^2}{4}(1-\cos 2\phi)\right] \quad (13)$$

The torque of the crankshaft,

$$T = \frac{F\times\sin(\phi+\beta)}{\cos\beta}\times R \quad (14)$$

Table 2: Matlab Results of Forces

ϕ (rad)	F_G 1.0e+003*	F_i 1.0e+003*	F 1.0e+003*	Q
0	0.0482	-1.4717	-1.4235	0
0.0005	0.0219	-1.1567	-1.1348	-158.8696
0.0010	-0.0026	-0.4139	-0.4165	-101.0031
0.0016	-0.0026	0.3219	0.3193	89.4097
0.0021	-0.0026	0.7358	0.7332	177.8003
0.0026	-0.0026	0.8348	0.8321	116.5003
0.0031	-0.0026	0.8278	0.8252	0.0000
0.0037	-0.0015	0.8348	0.8333	-116.6630
0.0042	0.0576	0.7358	0.7934	-192.3930
0.0047	0.1292	0.3219	0.4512	-126.3304
0.0052	0.3503	-0.4139	-0.0636	15.4331

0.0058	1.3909	-1.1567	0.2342	-32.7913
0.0063	4.9784	-1.4717	3.5067	-0.0000
0.0068	2.7113	-1.1567	1.5546	217.6390
0.0073	0.7683	-1.4139	0.3544	85.9409
79	0.3359	0.3219	0.6578	184.1838
0.0084	0.1972	0.7358	0.9331	226.2547
0.0089	0.1751	0.8348	1.0098	141.3771
0.0094	0.1670	0.8278	0.9948	0.0000
0.0099	0.1449	0.8348	0.9797	-137.1564
0.0105	0.0665	0.7358	0.8024	-194.5621
0.0110	0.0665	0.3219	0.3884	-108.7646
0.0115	0.0665	-0.4139	-0.3474	84.2412
0.0120	0.0665	-1.1567	-1.0902	152.6256
0.0126	0.0482	-1.4717	-1.4235	0.0000

Table 3: Matlab Results of Forces

ϕ (rad)	K 1.0e+003*	β	F_t	N 1.0e+003*
0	-1.4235	0	0	-1.4235
0.0005	-1.1459	0.1405	-412.2343	-0.9025
0.0010	-0.4288	0.2449	-706.2425	-0.1181
0.0016	0.3318	0.2838	318.5643	-0.0931
0.0021	0.7548	0.2449	542.6472	-0.5253
0.0026	0.8403	0.1405	314.1312	-0.7795
0.0031	0.8252	0.0000	0.0000	-0.8252
0.0037	0.8415	-0.1405	-314.5698	-0.7806
0.0042	0.8167	-0.2449	-587.1841	-0.5685
0.0047	0.4689	-0.2838	-450.1118	-0.1316
0.0052	-0.0655	-0.2449	62.9887	-0.0180
0.0058	0.2365	-0.1405	-145.7713	0.1863
0.0063	3.5067	-0.0000	-0.0000	3.5067
0.0068	1.5698	0.1405	967.4972	1.2364
0.0073	0.3648	0.2449	350.7596	0.1005
79	0.3836	0.2838	656.2415	-0.1919
0.0084	0.9605	0.2449	690.5304	-0.6685
0.0089	1.0197	0.1405	381.2089	-0.9459
0.0094	0.9948	0.0000	0.0000	-0.9948
0.0099	0.9893	-0.1405	-369.8283	-0.9177
0.0105	0.8260	-0.2449	-593.8045	-0.5749
0.0110	0.4037	-0.2838	-387.5253	-0.1133
0.0115	-0.3576	-0.2449	343.8224	-0.0985
0.0120	-1.1009	-0.1405	678.4853	-0.8671
0.0126	-1.4235	-0.0000	0.0000	-1.4235

Table 4: Matlab Results of Torque, Moment, Volume and Acceleration

ϕ (rad)	T	$M_{\phi oh}$ 1.0e+003*	Volume	Acceleratio[n] 1.0e+003*
0	0	3.6179	0	9.4704
0.0005	-30.0197	1.2428	10.4252	7.4433
0.0010	-17.5432	-0.1980	16.9158	2.6635
0.0016	13.5711	0.8910	17.7326	-2.0716
0.0021	23.0931	2.2922	13.7981	-4.7352
0.0026	13.3525	2.5494	7.3075	-5.3717
0.0031	0.0000	2.1662	0.0000	5.3271
0.0037	-13.3712	1.5630	-7.3075	-5.3717
0.0042	-24.9884	0.6195	-13.7981	-4.7352
0.0047	-19.1752	-0.2249	-17.7326	-2.0716
0.0052	2.6806	0.3068	-16.9158	2.6635
0.0058	-6.1962	-0.5174	-10.4252	7.4433
0.0063	-0.0000	-8.3448	-0.0000	9.4704
0.0068	41.1246	-1.3140	10.4252	7.4433
0.0073	14.9270	0.4719	16.9158	2.6635
79	27.9565	1.6618	17.7326	-2.0716
0.0084	29.3864	2.8722	13.7981	-4.7352
0.0089	16.2037	3.3588	7.3075	-5.3717
0.0094	0.0000	2.5778	0.0000	5.3271
0.0099	-15.7200	1.8088	-7.3075	-5.3717
0.0105	-25.2701	0.6246	-13.7981	-4.7352
0.0110	-16.5089	-0.1708	-17.7326	-2.0716
0.0115	14.6318	0.9438	-16.9158	2.6635
0.0120	28.8398	3.3351	-10.4252	7.4433
0.0126	0.0000	3.6179	-0.0000	9.4704

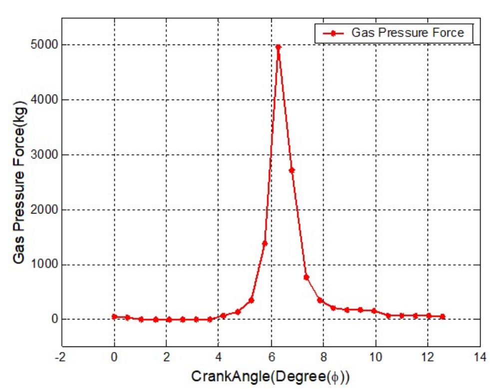

Fig. 2 Gas Pressure Force with Crank Angle

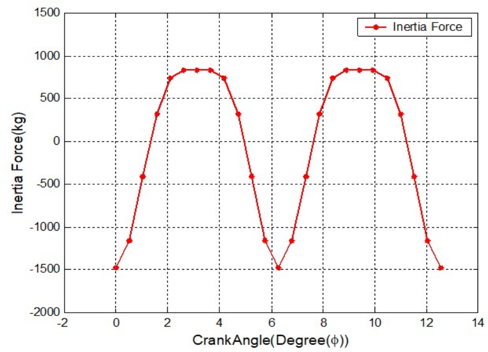

Fig. 3 Inertia Force with Crank Angle

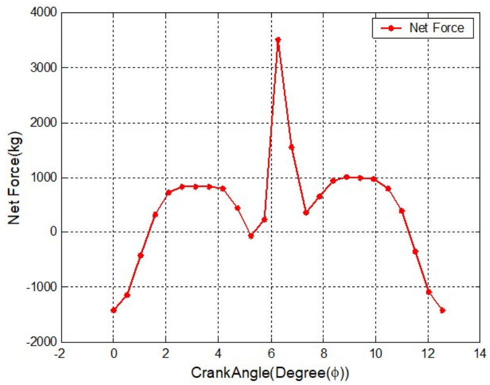

Fig. 4 Net Force with Crank Angle

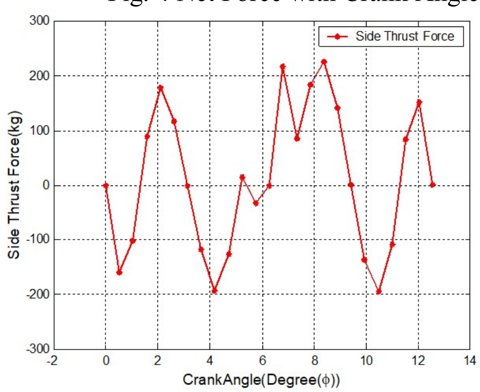

Fig. 5 Side Thrust Force with Crank Angle

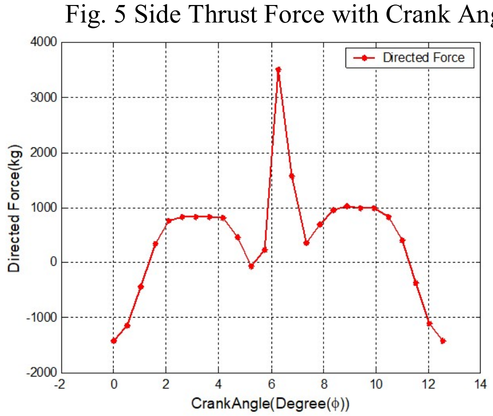

Fig. 6 Directed Force with Crank Angle

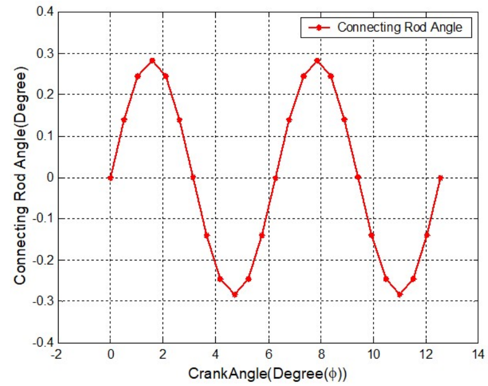

Fig. 7 Connecting Rod Anglewith Crank Angle

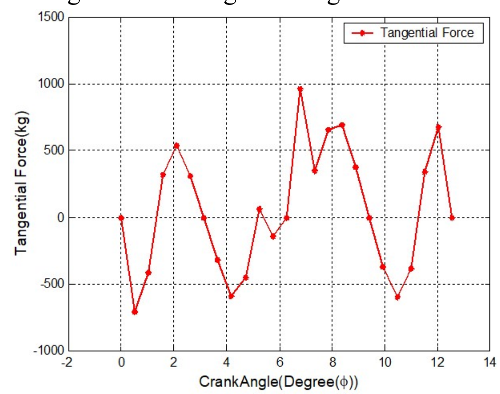

Fig. 8 Tangential Forcewith Crank Angle

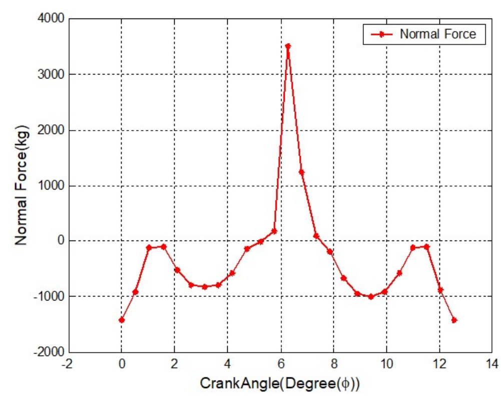

Fig. 9 Normal Force with Crank Angle

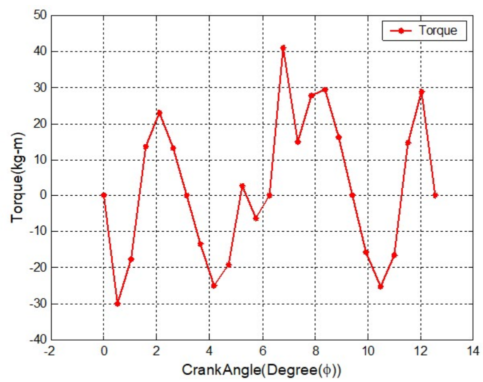

Fig. 10 Torquewith Crank Angle

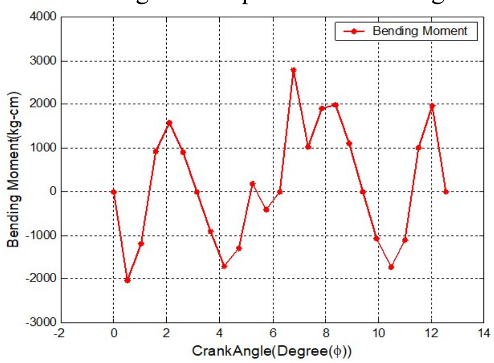

Fig. 11 Bending Momentwith Crank Angle

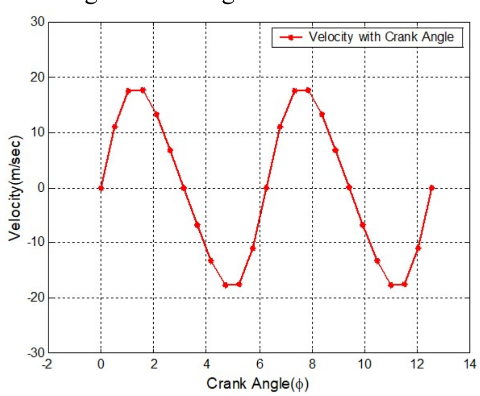

Fig. 12 Velocitywith Crank Angle

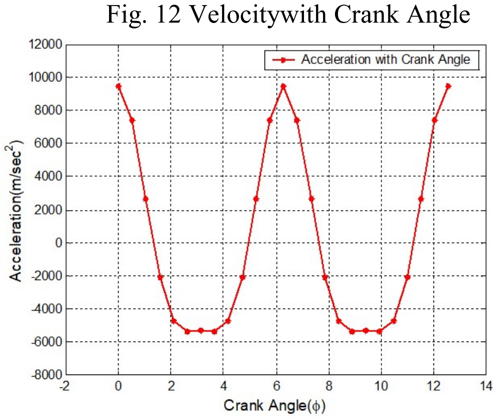

Fig. 13 Accelerationwith Crank Angle

IV. RESULTS AND DISCUSSION

The calculation of engine parameters is required to get gas forces. The calculated results of engine parameters are shown in TABLE I. These engine parameters were used to draw the indicator diagram as shown in Fig. 1. The gas pressures were read from this diagram. Then, gas forces were calculated from gas pressures. The inertia forces were also evaluated from the reciprocating (piston) mass. The net force is the difference between inertia forces and gas force. The transmitted force, normal force along the crank radius, side force and force through the connecting rod are determined from the net force. The calculated results of torque, tilting moment, and forces were also shown in TABLE II, III and IV. Torque, tilting moment, and forces depend on the angle of crank travel. The maximum connecting rod angle is 15°.

V. CONCLUSION

In kinematics, forces acting on the crankshaft depend on the angle of crank travel. The angle of connecting rod may also be evaluated from the length of connecting rod and radius of crank. Material selection is also important in the design consideration of crankshaft, because crankshaft is subjected to shock and fatigue loads. The crankshaft is loaded by perpendicular forces of gas pressure and forces of inertia of reciprocating and rotating masses. Therefore, the following factors should be considered in design of crankshaft.

1. The shaft must be strength, rigid and have a good resistance to wear, but have a relative low weight.
2. The especially high accuracy of manufacture crank pin and main journal must be provided.
3. The crankshaft must be statically and dynamically balanced.

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