

University of Wales Trinity Saint David

School of Engineering

Con-Rod Accelerations, Forces &
Displacements

Advanced Engine Design M6X00410

Zhangwei Guo

1805078

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Notation of Engine Data

Quantity	Notation	Production Engine	Modified Engine	Unit
Mass of Piston	M pis	0.350	0.355	kg
Radius of the Crank	R	0.047	0.040	m
Length of Rod	L	0.134	0.124	m
Length of Shank	L Shank	0.100	0.090	m
Diameter of Bore	D	0.079	0.080	m
Cross-Sectional Area	CSA	195	195	mm ²
Ultimate Tensile Strength	UTS	750	750	N/mm ²
Youngs Modules of Steel	E Steel	20500	20500	N/mm ²
Youngs Modules of Titanium	E Titanium	105000	105000	N/mm ²

1 Abstract

After learning the corresponding professional knowledge in the lecture, Microsoft Excel® has been used to preliminarily process the obtained raw engine data and the related parameters obtained by searching. The preliminary data obtained from this is compared horizontally and vertically for curve drawing. Trying to find the required parameter points and organize them into a table. By comparing these results at different speed, the effect of the rotational speed on them can be obtained. At the same time, the analysis of the analytical parameters of production engine and modified engine demonstrates the feasibility and practical value of the modification scheme. The analysis of modified engine is based on the RPM of 5000.

2 Peak Gas Force

The force acting on the piston during the combustion process of the in-cylinder mixed gas which called gas force is finally applied to the crankshaft through the connecting rod, which is the most important way of working in the engine.

2.1 Principle of analysis

Equation (1) as follows is used to get the force of gas from the original tested data.

$$Force = Pressure \times Area \quad (1)$$

The maximum Pressure has to be found to get the peak gas force as Equation (2) shows as the area is the area of bore which is stable.

$$Max\ Gas\ Force = Peak\ Pressure \times Bore\ Area \quad (2)$$

2.2 Result display

RPM	Angle	Peak Gas Force
1000	28	22526.605
1500	31	28363.023
1700	29	32397.710
2000	26	35531.470
2500	25	37575.466
3000	25	39111.037
3500	24	40468.922
4000	23	41573.146
4500	24	41324.141
5000	24	42759.718
5500	21	45579.771
5700	20	46690.857
6000	18	46862.906

Table 2-1 Peak Gas Force of different RPM

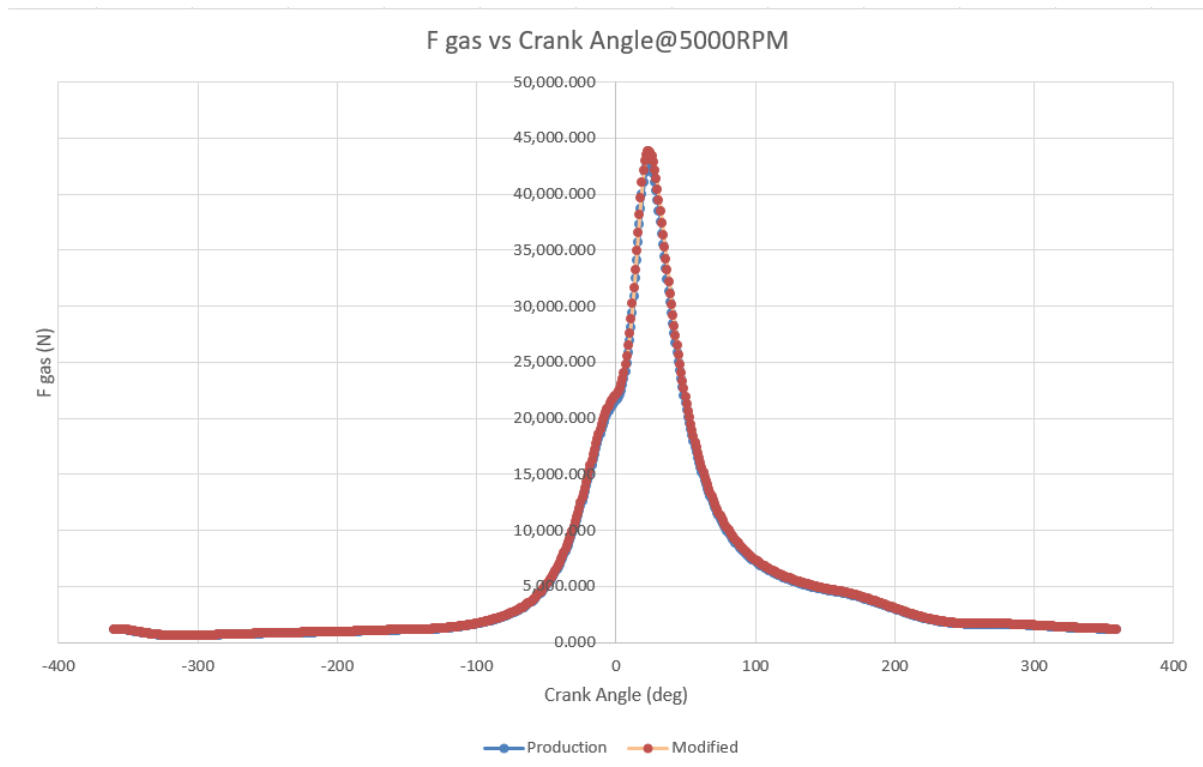


Figure 2-2F gas vs Crank Angle@5000RPM

@5000RPM	Degree	Peak Gas Force
Production	24	42759.718
Modified	24	43849.094

Table 2-2 Peak Gas Force

2.3 Result analysis

Modified data from table 2-1 shows that peak gas force increases according to the RPM but still around the crank angle of 25. Graph within figure 2-1 suggests their trendlines are quite similar with different peak gas force which due to the same pressure data has been used with different bore diameters which related to the area in the calculation.

3 Inertia Forces

In addition to the gas force, the connecting rod is subjected to another force called inertia force which is caused by the mass of piston.

3.1 Principle of analysis

It can be obtained through Equation (3) shown below. As we can see this Inertia force has two parts like 1st order and 2nd order Inertia force in Equation (4) and (5).

$$F_{inertia} = M_{piston}(R\omega^2 \cos\theta + \left(\frac{R}{l}\right) R\omega^2 \cos 2\theta) \quad (3)$$

$$1st\ Order\ Inertia = M_{piston} R\omega^2 \cos\theta \quad (4)$$

$$2nd\ Order\ Inertia = M_{piston} \left(\frac{R}{l}\right) R\omega^2 \cos 2\theta \quad (5)$$

3.2 Result display

RPM	Angle	Maximum Inertia Load
1000	0	243.946
1500	0	848.878
1700	0	705.003
2000	0	975.782
2500	0	1524.660
3000	0	2195.510
3500	0	2988.333
4000	0	3903.129
4500	0	4939.898
5000	0	6098.640
5500	0	7379.354
5700	0	7925.792
6000	0	8782.041

Table 3-1 Maximum Inertial Load of different RPM

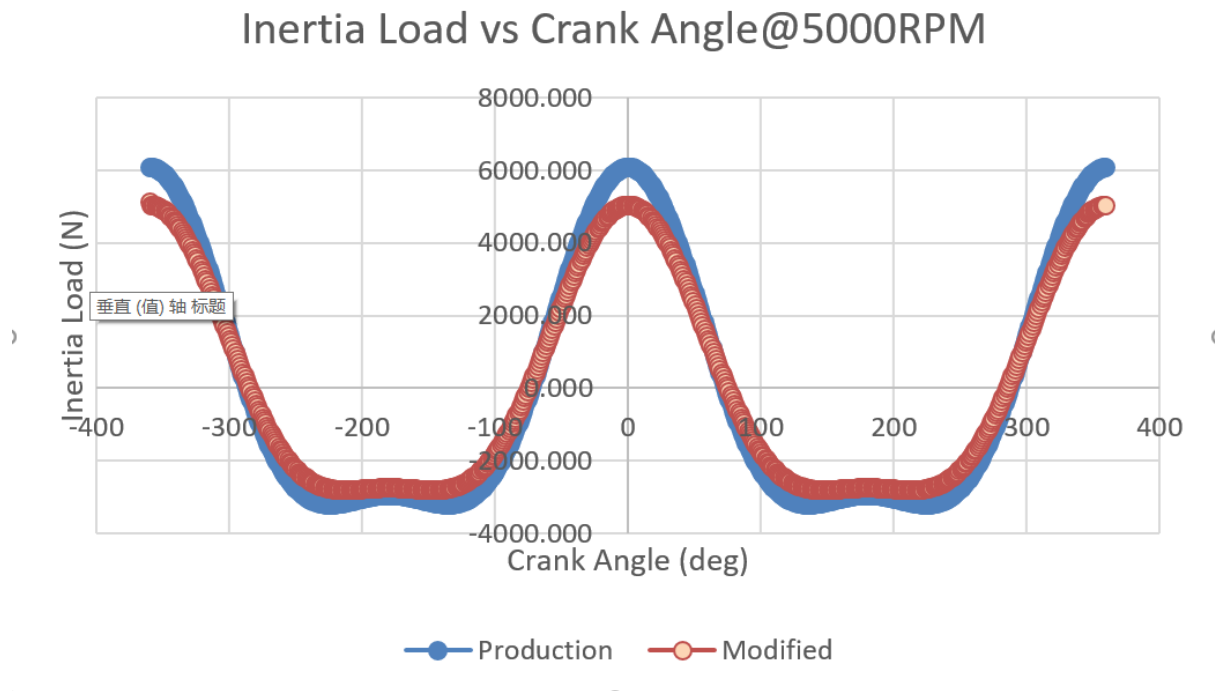


Figure 3-1 Inertia Load vs Crank Angle

@5000RPM	Degree	Maximum Inertia Load
Production	-1/1	6096.987
Modified	0	5060.799

Table 3-2 Maximum Inertia Load

3.3 Result analysis

As table 3-1 shows, the inertia load increases rapidly with increasing speed and inertia load getting the maximum when the crank angle is zero is stable which is reasonable which can be seen from Equation (3).

First of all, the mass of the piston affects the inertia load hugely. After that the maximum inertia load always around the crank angle of zero due to the piston suddenly stops at TDC while the crank changes the direction.

It is obvious there is a problem with the data point of the first degree which should be zero in table 3-2. That should be analysed within systematic error analysis.

4 Compressive Force.

The connecting rod acts as a stressed component which is under pressure mostly, but every material has Ultimate Tensile Strength. Once the stress from compressive above that value, the material loses its original strength. So the highest compressive force needs to be found.

4.1 Principle of analysis

To get the force in rod, net force has to be obtained with Equation (6) firstly as force in rod has the relationship as shown in Equation (7) with net force.

$$F_{Net} = F_{Gas} - F_{Inertia} \quad (6)$$

$$F_{Rod} = \frac{F_{Net}}{\cos\varphi} = (F_{Gas} - F_{Inertia}) / \cos\varphi \quad (7)$$

4.2 Result display

RPM	Angle	Max Net Force
1000	28	22331.722
1500	31	27947.800
1700	29	31844.204
2000	26	34726.183
2500	25	36297.985
3000	25	37271.463
3500	24	37928.604
4000	23	38209.196
4500	24	37124.839
5000	24	37575.394
5500	21	39055.460
5700	20	39600.430
6000	19	38915.320

Table 4-1 Highest Net Force of different RPM

Net Force vs Crank Angle @5000RPM

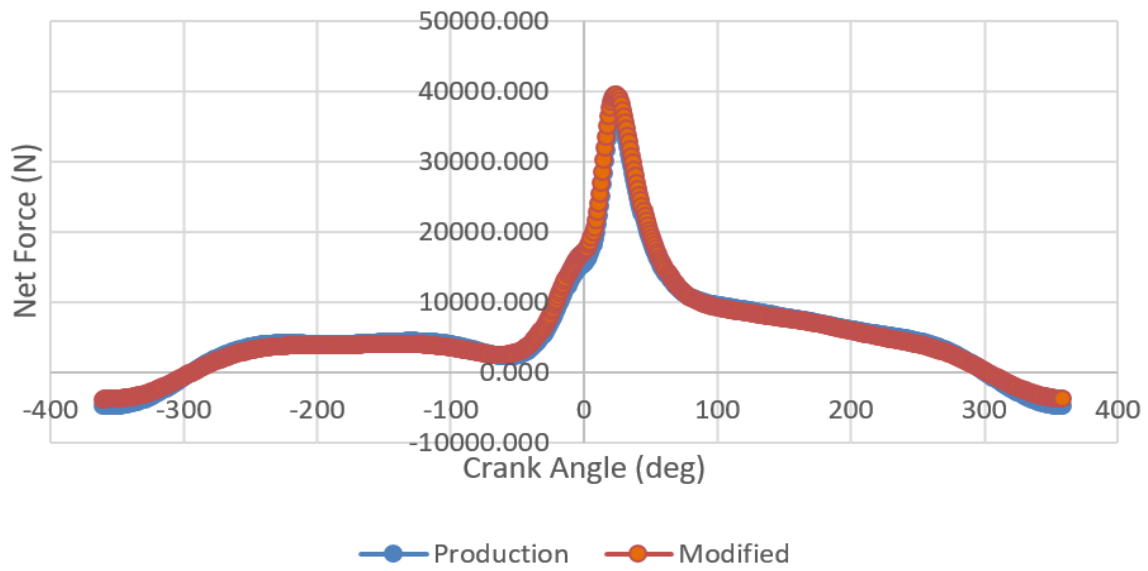


Figure 4-2 Net Force vs Crank Angle

@5000RPM	Degree	Max Net Force
Production	24	37575.394
Modified	24	39510.176

Table 4-2 Max Net Force

RPM	Angle	Max Compressive Force
1000	28	22640.780
1500	31	28415.292
1700	29	32314.828
2000	26	35144.092
2500	25	36703.461
3000	25	37687.814
3500	24	38320.564
4000	23	38573.154
4500	24	37508.493
5000	24	37963.704
5500	21	39367.694
5700	20	39888.487
6000	19	39171.552

Table 4-3 Highest Compressive Force of different RPM

Compressive Force vs Crank Angle @5000

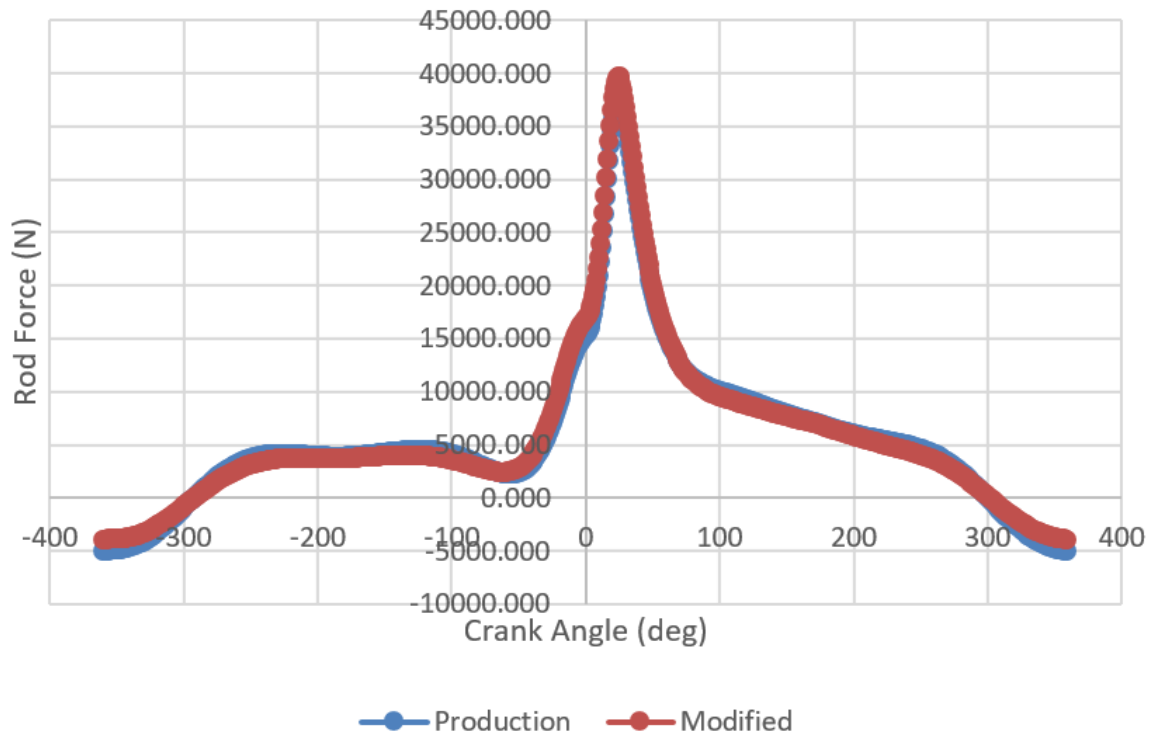


Figure 4-2 Compressive force vs Crank Angle

@5700RPM	Degree	Max Compressive Force
Production	20	39888.487
Modified	20	42323.794

Table 4-4 Max Compressive Force

4.3 Result analysis

According to the analysis of the above chart, both of net force and compressive force increase first and then decrease with the increase of the speed and have the highest value when the speed is 5700 rather than 6000. The highest net compressive force on rod is 39888.487 N @5700RPM.

5 Tensile Force

As a force-receiving part, the connecting rod not always under pressure, sometimes it is subjected to tensile force as well.

5.1 Principle of analysis

Since the upper part has calculated the compressive force applied to the connecting rod, the calculation of tensile force can be directly performed using Equation (6) and (7) due to the tensile force and the compressive force are only the opposite values. At the same time, the biggest tensile force appears at TDC on account of the stop of the piston. So Equation (8) could also been used which $\cos\theta$ is replaced with 1 when the rod is vertical completely.

$$F_{Ten} = M_{Piston}R\omega^2\left(1 + \frac{R}{L}\right) \quad (8)$$

5.2 Result display

RPM	Highest Tensile Force
2000	275.334
2500	809.506
3000	1355.732
3500	2133.482
4000	2971.444
4500	3925.252
5000	4952.629
5500	6108.228
5700	6638.614
6000	7451.973

Table 5-1 Highest Tensile Force of different RPM

@6000RPM	Highest Tensile Force
Production	7451.973
Modified	3824.554

Table 5-2 Highest Tensile Force

The highest net tensile load on rod is 7451.973 N @6000RPM.

6 Stress in Rod

For the calculation of stress, CSA (cross-sectional area) needs to be obtained firstly. CAS could be easily calculated with the parameters measured in lecture using the assumption of simple rectangular beam.

6.1 Compressive Stress

Since the highest compressive force occurs at 5700RPM, maximum compression stress can be obtained through equation (9)

$$\sigma = \frac{\text{Force}}{\text{Area}} \quad (9)$$

@5700RPM	Highest Compressive Force (N)	Maximum Compression Stress (MPa)
Production	39888.487	204.556
Modified	42323.794	217.045

Table 6-1 Maximum Compression Stress

6.2 Tensile Stress

The same equation (9) could be used to calculate tensile stress as well. The max tensile force occurs at 6000RPM on which the max tensile stress appears.

@6000RPM	Highest Tensile Force (N)	Maximum Tensile Stress (MPa)
Production	7451.973	38.215
Modified	3824.554	19.613

Table 6-2 Maximum Tensile Stress

7 Safety Factors

Safety factors are ratios between ultimate strength and the maximum stress in the rod which are used to make sure the structure could be safe. Safety factors can be calculated through Equation (10) and the results are as followed in table 7-1.

$$Safety\ Factor = \frac{UTS}{\sigma} \quad (10)$$

Safety Factors	Compression	Tensile
Production	3.666	19.626
Modified	3.456	38.240

Table 7-1 Safety Factors

8 Strain

When author trying to get the compression and stretch, length of shank needs to be determined is realized. It normally comes between 55%~65% over the length of rod (Schoeffmann Wolfgang, 2017). So I assume the length of shank to be 0.1m.

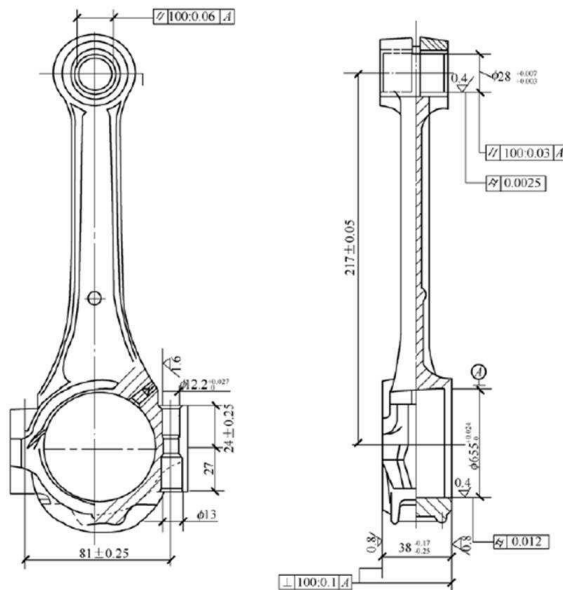


Figure 8-1 (Schoeffmann Wolfgang, 2017)

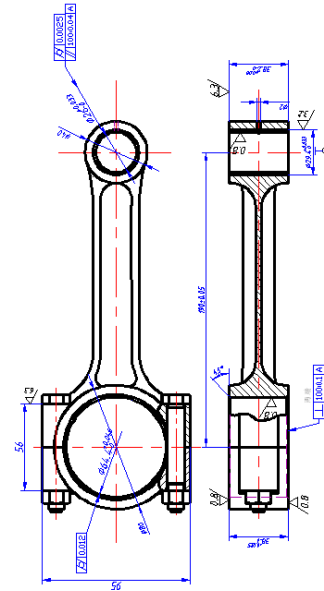


Figure 8-2 (Schoeffmann Wolfgang, 2017)

Since both the stress and young's modulus all have been got, the strain of compression and tension can be obtained through formula (11), (12) and (13).

$$E = \frac{\text{Stress}}{\text{Strain}} \quad (11)$$

$$E = \frac{F}{\frac{\Delta}{L}} \quad (12)$$

$$X = \frac{F * L}{E * A} \quad (13)$$

Strain	Compression (mm)	Tension (mm)
Production	0.016960	0.091043
Modified	0.012436	0.096298

Table 8-1 Changes in Length (Steel)

9 Titanium

9.1 Result display

There is a difference of the density between titanium and steel which means the size of rod can increase without any extra mass. (Ward, 2014)

Strain	Compression (mm)	Tension (mm)
Production	0.003311	0.017775
Modified	0.002428	0.018801

Table 9-1 Changes in Length (Titanium)

9.2 Result analysis

From the analysis of the data obtained from the treatment, changes from titanium are much smaller than steel in both of compression and tension which means it will be better to keep the engine operating clearance.

10 Conclusion

Through the completion of this assignment, the understanding of the knowledge learned in the lecture has been fully deepened. A more comprehensive understanding of the engine piston, connecting rod and crankshaft movement has been achieved. The effect and feasibility of the modification can be more intuitively displayed through the way of comparing all the parameters of production engine and modified engine.

There are still many completed tasks such as side wall force, friction, work and energy loss that cannot be written due to the limit of words. There are still many aspects that are not accurate enough for the work that has already been done. For example, the mass involved in calculating the inertial load will be more accurate if the result is made with FEA. Various lengths, diameters and depth dimensions would be much more accurate with professional measurement tools.

11 References

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12 Appendix

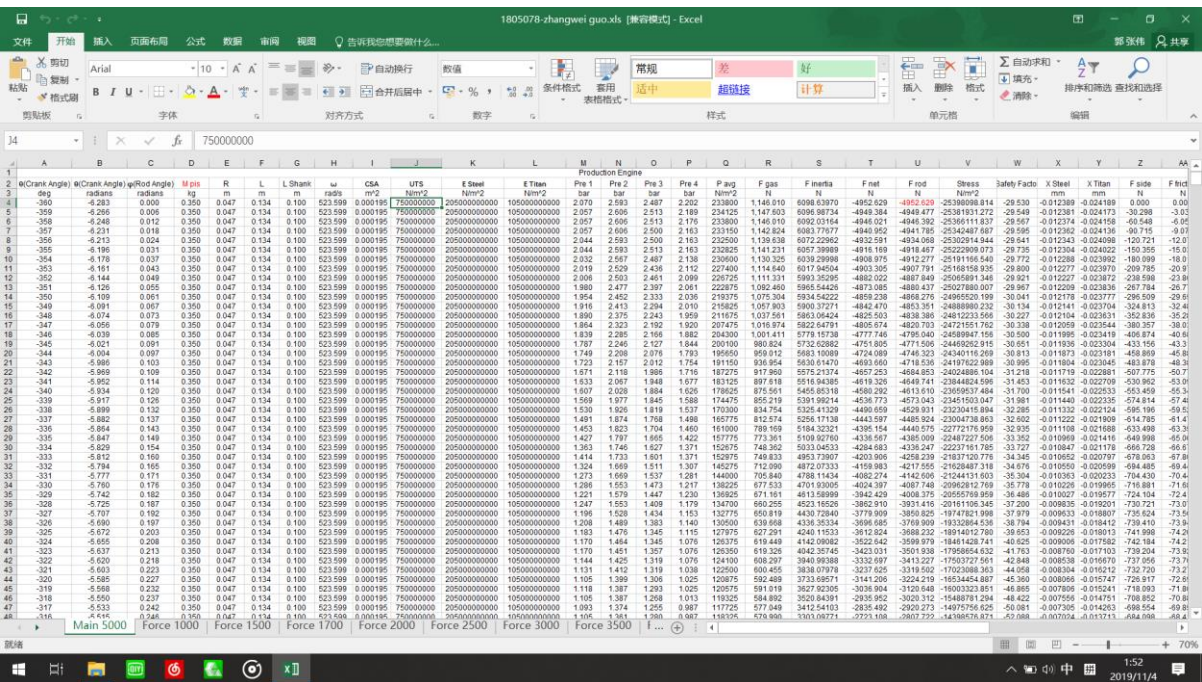


Figure 12-1

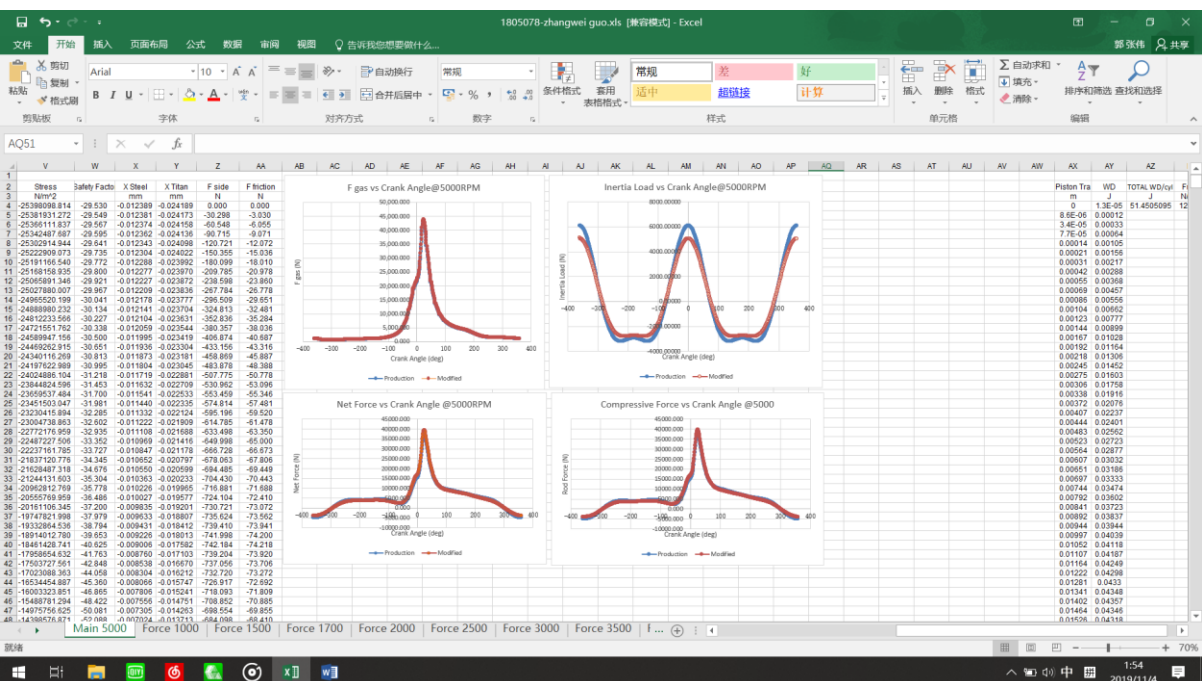


Figure 12-2

