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Sensitivity Study of a Valve Recession Model

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Abstract

The aim of this work was to carry out a sensitivity analysis of a valve recession model. For the sensitivity study, the effects of the parameters on the valve recession model were investigated, for both, light duty and heavy duty engines. For light duty engines, it was observed that the impact wear of component parameters had the greatest effect on valve recession and for heavy duty engines, the sliding wear of component parameters had an increasing contribution to the overall valve recession.

Keywords

Valve-Seat Insert, Recession Modelling, Sensitivity Study

1. Introduction

Diesel engines are subjected to high thermal and mechanical stresses, and are exposed to loads resulting from impact on valve closure, combustion pressures and high temperatures [1]. Some types of valve failure have been observed. The main are valve recession, guttering and torching [2]. Valve recession failure happens when the valve penetrates or recedes into the seat insert, altering the closed position of the valve relative to the cylinder head [2]. It has been suggested that it may occur by some wear mechanisms like metal abrasion, fretting, adhesion mechanisms, impact and high temperature corrosion [3]. Other works have been done to study the wear when it occurs in conjunction with oxidation and elevated temperatures [4] [5] [6]. The mechanisms of valve wear, larger seat angles and lower friction coefficients cause higher normal forces and more wedging between the valve face and insert [7].

Not many models exist to predict valve or seat insert life. One study [8] reports the development of a model for valve recession. The model provides a quantitative analysis of valve recession and considers two fundamental wear mechanisms identified as causing valve recession (impact and sliding) separately. The wear mechanisms were put together to obtain the final model. The model works well, for both engine tests and tests run on a bench test rig. Another study [9] reports the development of a wear model for exhaust valves in diesel engines.

The aim of this work was to investigate the effect of the parameters on a valve recession model [8], carrying out a sensitivity analysis of the model, for both light duty engines (passenger cars, etc.) and heavy duty engines (marine, etc.). One of the weaknesses of the recession model described is the lack of friction and data of wear coefficient. This further understanding and improvement in the modelling will allow the reduction of engine testing programs, identification of ideal material properties for valves and seat inserts, and optimization of the size and geometry. All this will then help enhance the life of the valves and seats.

Valve Recession Modelling and Sensitivity Analysis Approach

A valve recession model [8] combines the impact and sliding mechanisms. The wear volume V is determined by Equation (1).

$$\boldsymbol{V} = \left(\frac{\boldsymbol{kPN}\delta}{\boldsymbol{h}} + \boldsymbol{KNe}^{n} \right) \left(\frac{\boldsymbol{A}_i}{\boldsymbol{A}} \right)^{j} \quad (1)$$

where k is a sliding wear coefficient, P is the load at the valve seat interface, N is the number of cycles, h is the hardness, δ is the slip at the interface during combustion in the cylinder, K and n are impact wear coefficients and e is the impact energy on valve closure (given by 1/2 mv^2, where m is the valve and follower mass and v is the valve closing velocity), A_i is the initial valve/seat contact area, A is the contact area after N cycles and j is a constant determine dempirically using bench and engine test data [8]. The recession is then calculated using Equation (2) for the case where valve and seat angles are equal [4].

$$\boldsymbol{r} = \left(\sqrt{\frac{\boldsymbol{V}}{\pi \boldsymbol{R}_i \cos\theta_s \sin\theta_s} + \boldsymbol{w}_i^{2}} - \boldsymbol{w}_i \right) \sin\theta_s \quad (2)$$

where R_i is the initial seat insert radius, θ_s is the seat insert seating face angle and w_i is the initial seat insert seating face width (as measured).

On the other hand, the objective of the sensitivity analysis is to identify sensitive recession model parameters whose values can be changed without changing the final recession. The methodology used in this work was as follows [10].

Identify all the parameters that can change the response of the model.

Set a range of values for each parameter based on two engine types ("light duty" and "heavy duty" in addition to a typical set of baseline values).

Use a version of the model described above set-up in MatLab to simulate the recession response, varying each parameter within their established ranges, leaving all other parameters at their baseline value.

Determine for each parameter the recession values, and calculate the difference from the baseline recession value.

Finally determine which parameters had the greater and least effect on recession value.

Table 1 shows the parameter ranges and base values, for both engines classes.

They were chosen referring to data from leading manufacturers/users of valves and seat inserts.

2. Sensitivity Analysis Results

Figure 1 shows the parameters that had the greater and least effect or grade of influence on valve recession, for light duty and heavy duty engines. The graphs show the grade of incidence, high to low, of the parameters analyzed. The graphs also show the maximum and minimum values of the recession for each parameter as well as the baseline value of the recession (red line).

As explained, two components contribute to the overall recession, which is produced by the sliding effect of the valve on the seat insert in the combustion stage and the recession caused by the impact of the valve on the seat.

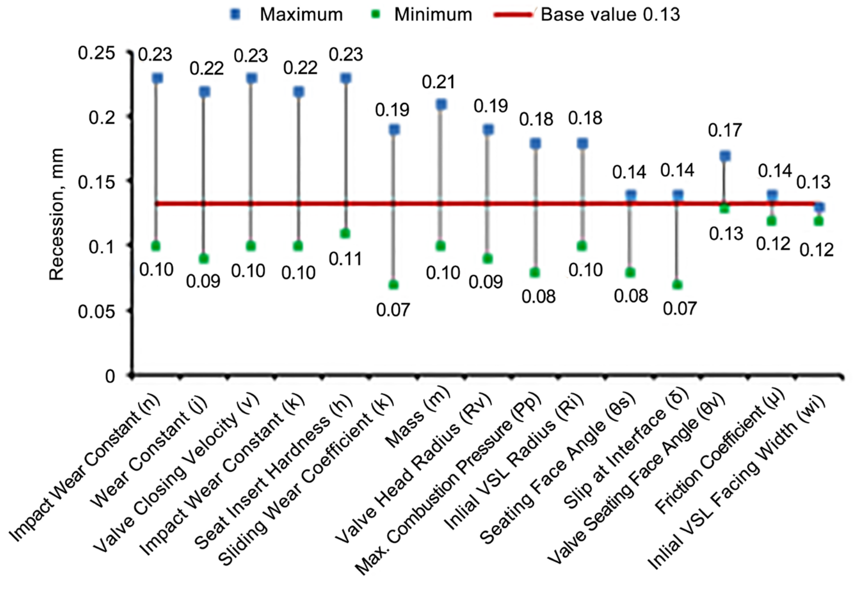
In light duty engines, where the valve closure velocity is relatively high, a greater effect of the impact component than the sliding component is apparent. The opposite happens for heavy duty engines, where the valve velocity is relatively low and the sliding between valve and seat is very large due to the combustion and the higher sliding due to the increased valve head size.

It is observed that for light duty engines (Figure 1(a)); parameters

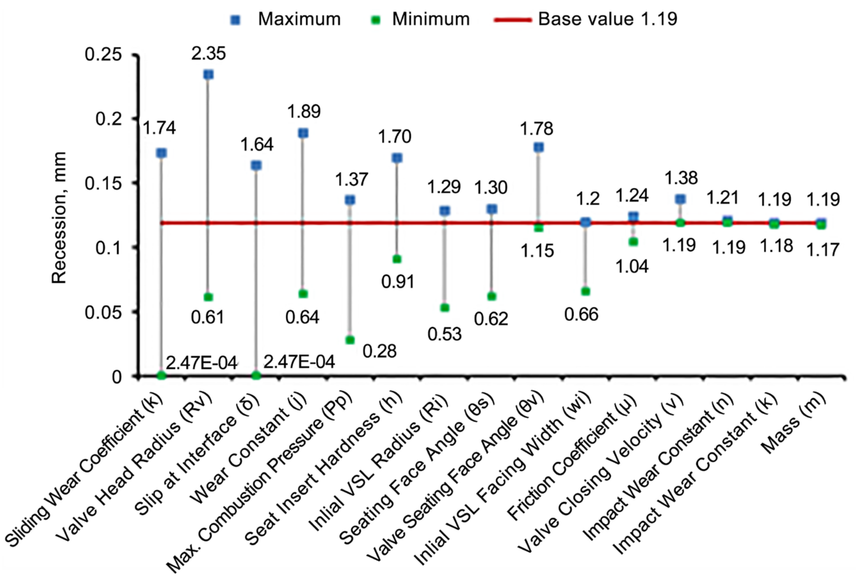
Table 1. Parameter ranges for light and heavy duty engines.

Calc.	Parameter Name	Baseline Value		Parameter Ranges	
		Light Duty Engines	Heavy Duty Engines	Light Duty Engines	Heavy Duty Engines
Sliding Wear Volume	Friction Coefficient, μ	0.1	0.1	0 - 0.5	0 - 0.5
	Max. Combustion Pressure, P_p (MPa)	13	13	1 - 30	1 - 30
	Valve Head Radius, R_v (m)	0.018	0.1	0.008 - 0.03	0.05 - 0.5
	Valve Seating Face Angle, θ_v (˚)	45	45	20 - 50	20 - 50
	Seat Insert Hardness, h (MPa)	4900	4900	1000 - 9000	1000 - 9000
	Sliding Wear Coefficient, k	5.0E−05	5.0E−05	0 - 1.0E−03	0 - 1.0E−03
	Slip at Interface, δ (m)	8.0E−06	0.2E−03	0 - 1.0E−05	0 - 5E−03
Impact Wear Volume	Impact Wear Constant, K	5.0E−14	5.0E−14	1.0E−18 - 1.0E−11	1.0E−18 - 1.0E−11
	Impact Wear Constant, n	1	1	0.1 - 4	0.1 - 4
	Valve Closing Velocity, v (m/s)	0.3	0.01	0 - 2.5	0 - 1
	Mass, m (kg)	0.182	10	0 - 0.75	0 - 350
	Total Number of Cycles, N	50,000,000	50,000,000	N/A	N/A
Recession	Seating Face Angle, θ_s (˚)	45	45	20 - 50	20 - 50
	Initial VSI* Facing Width, w_i (m)	2.0E−03	0.012	0.8E−03 - 6.0E−03	5E−03 - 80E−03
	Initial VSI* Radius, R_i (m)	0.0168	0.095	0.008 - 0.03	0.05 - 0.5
	Wear Constant, j	10	10	3 - 20	3 - 20

*VSI = Valve Seat Insert.



(a)



(b)

Figure 1. Recesion parameters: (a) for light duty engines; (b) for heavy duty engines.

corresponding to the impact component (*n, v, K*) have the greatest effect on the overall recession, because in these engines the valve moves at high velocity, increasing the impact energy. On the contrary, it can be seen that, the sliding wear components have a lower effect on the recession.

On the other hand, **Figure 1(b)** shows that the parameters that had the greatest effect on the recession of heavy duty engines were those corresponding to the sliding wear component such as k, δ, P_p and h.

Moreover, the parameters corresponding to the impact component, *v, n, K* and *m*, gave maximum and minimum recession values very close to the baseline value, indicating that their impact on the overall recession is very small, this is because this type of engines work at low velocities, due to its large mass resulting in a low effect on the energy of impact. These results coincide with those presented in other work reported [11].

In the work reported by Blau [9], the wear modelling process for diesel engines exhaust valves was developed. The model is intended to compute the cross-sectional area on valve and seat due to wear and displacement of material. Thus, the abrasion and displacements, of both valve and seat materials, are added. The main differences between the Lewis & Slatter model and the Blau model are: Lewis & Slatter model calculates the Valve Recession while Blau model calculates de Worn Area and Lewis & Slatter model does not consider the temperature parameter while Blau model considers it. Equation (3) calculates the total area of the worn area (A_p) in a profile of the valve/seat combination after n cycles [9].

$$\begin{aligned} A_p(n) &= \left[A_{disp}(n)\right]_{valve} + \left[A_{disp}(n)\right]_{seat} \\ &\quad + \mu_T p c_{a4}\left\{k*_{valve}\left[S(n)\right]_{valve} + k*_{seat}\left[S(n)\right]_{seat}\right\} \end{aligned} \tag{3}$$

where A_{disp} is the projected area of displaced volume in the plane that contains the valve seat incline, μ_T is the kinetic friction coefficient at the valve/seat interface at temperature T, p is the maximum combustion pressure in the cylinder, c_{a4} is the valve geometrical constant, $k*$ is the projected area (profile) abrasive wear rate of the surface at a seat angle of 45˚ and $S(n)$ is the cumulative sliding distance.

Figure 2 shows the results for valve recession between the Lewis & Slatter model and the Blau Model. It can be seen that the Blau model has a linear behaviour and the value for valve recession was bigger, maybe because the effect of corrosion caused by the temperature parameter. The data used to run the developed program were the same used in the MatLab program for Lewis and Slatter model.

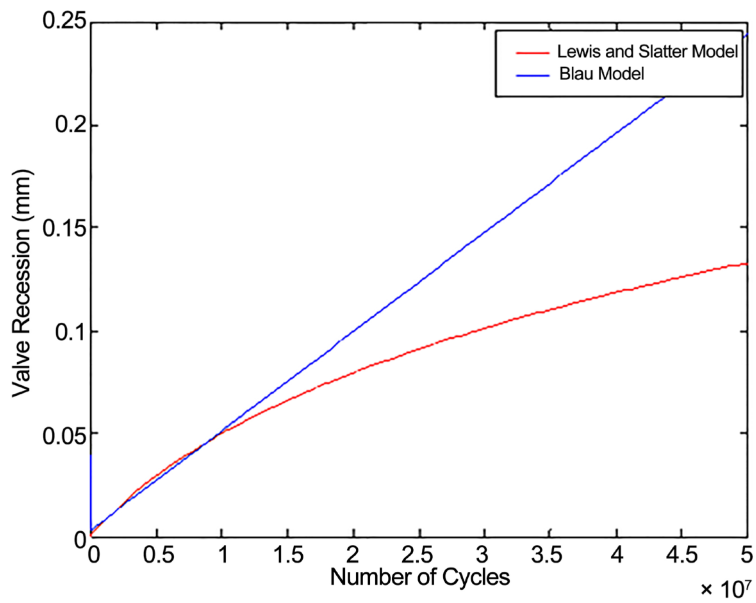


Figure 2. Comparison between the Lewis & Slatter model and Blau model.

3. Conclusions

Valve specimens made of martensitic low alloy steel were put in frictional sliding tests against seat insert specimens made of cast tool steel. The work reports the sensitivity analysis carried out on a valve recession model, concluded the following.

For light duty engines, the impact wear of component parameters had the greatest effect on valve recession.

For heavy duty engines, the sliding wear of component parameters has an increasing contribution to the overall valve recession.

Modelling applied to tribological systems provides a reliable alternative in situations where experimental process is not easy to carry out, especially when there are many variables that affect the system.

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