

A Combined Mathematical & Experimental Approach to Valvetrain Dynamics Based on an MCR Duratec Engine

George Jones

Supervisor: Malcolm McDonald

School of Engineering

BEng (Hons) Motorsport Engineering



Introduction

This project was inspired by the SRCC Sports 2000 Championship technical regulations, where limited elements of the engine are permitted for development.

Experimental procedures were refined in Matlab to convert between measured camshaft & valve lift, using the matrix method and coordinate geometry. A Mathematical model was then produced to calculate cam-to-tappet friction. Harmonic analysis was carried out for determining valve spring surge characteristics, using the Fourier series. All findings were compared against commercial valve lift profiles [1],[2].

Measured Cam Lift to Valve Lift

The elected cam lobe measuring procedure introduced noise to higher order derivatives of lift. This was significantly improved by using a blended Gaussian-Polynomial curve fit [3]. The valve lift matrix study introduced further noise. This was refined by interpolating the original 360 measurements (1° cam angle) to:

- 0.5 ° = (720 x 720)
- 0.1 ° = (3,600 x 3,600)
- 0.01 ° = (36,000 x 36,000)

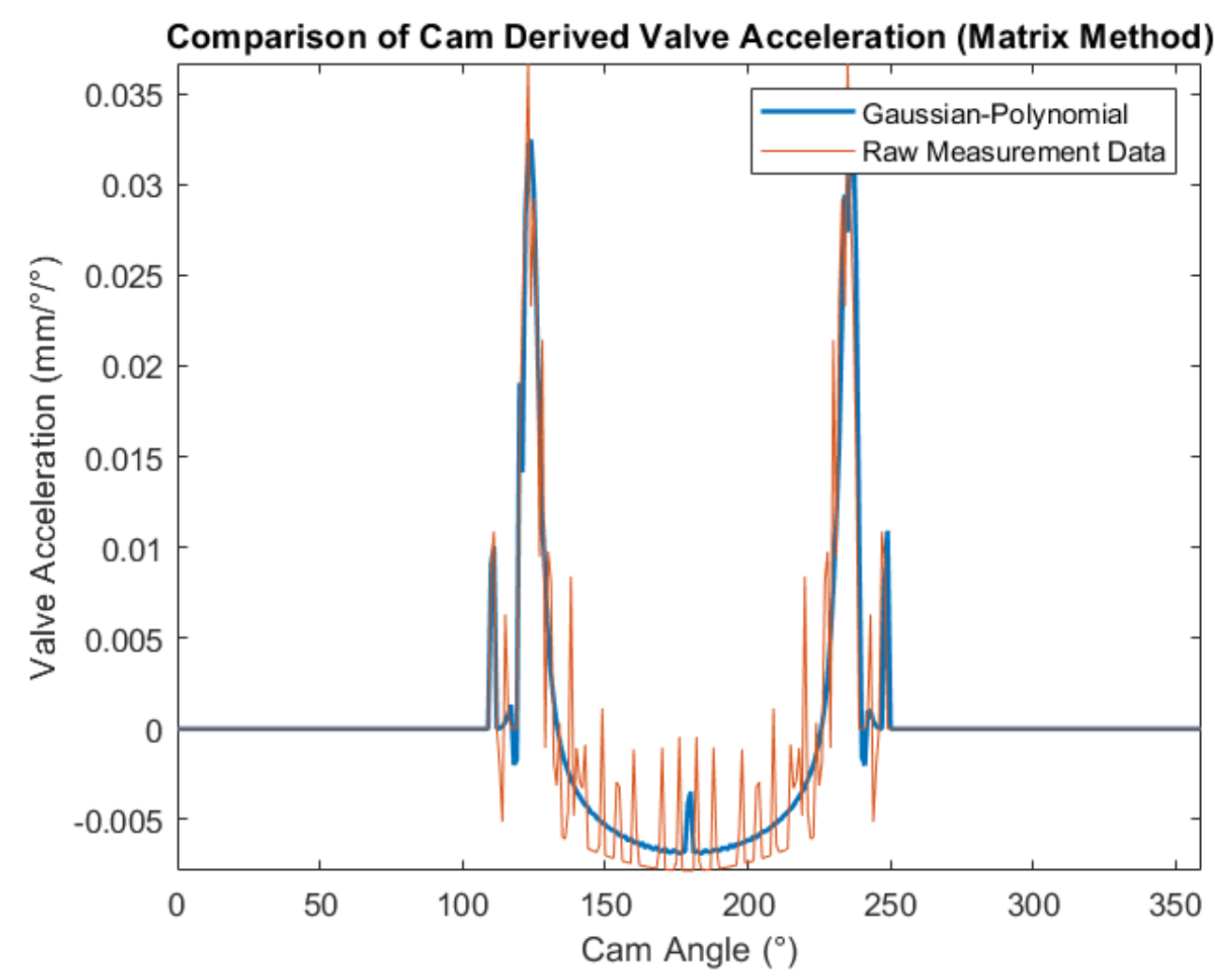
```
% VALVE LIFT MATRIX (36,000 x 36,000) [0.01 DEGREE INCREMENTS]
% Phi vector in 0.01 deg steps
PhiD = (0 :0.01: 359.99); % ADJUST FOR 0.01 deg steps

% Extend 360 values to 36,000 values

Vi = RLI'; % Original 360 ROW VECTOR
[ri,ci] = size(Vi);
p = 99; % number of NaN to be inserted between each values of V
Vf36k = NaN(1,ci*(p+1)-p);
[rf,cf] = size(Vf36k);
k = 1;
for i = 1:p+1:cf
    Vf36k(i) = Vi(k);
    k = k+1;
end
Vf36k; % RESULTANT EXTENDED VECTOR

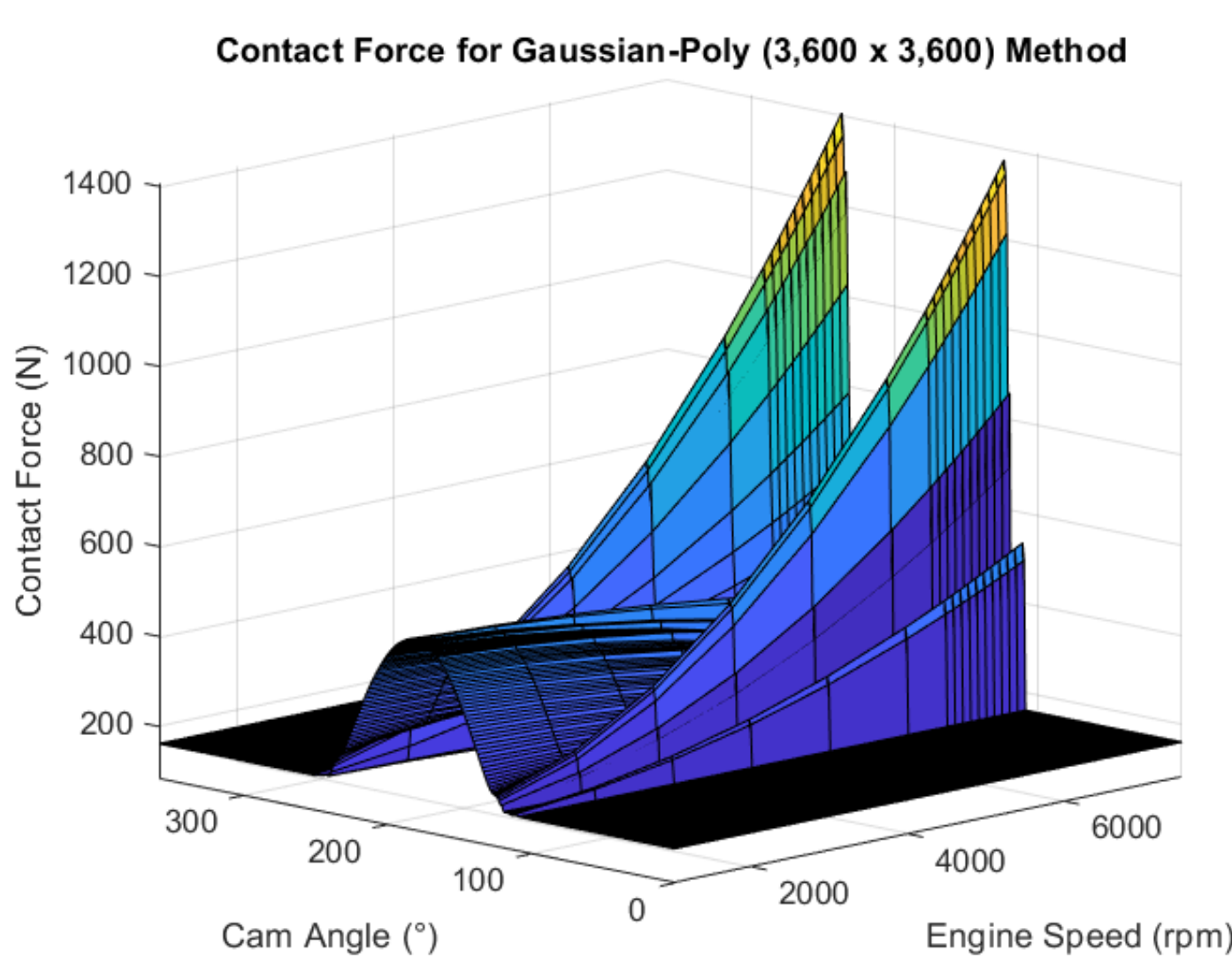
Vector36k = fillmissing(Vf36k, 'pchip'); % INTERPOLATION COMMAND
```

Example of Matlab script for expansion and interpolation of cam measurement data before running the matrix.



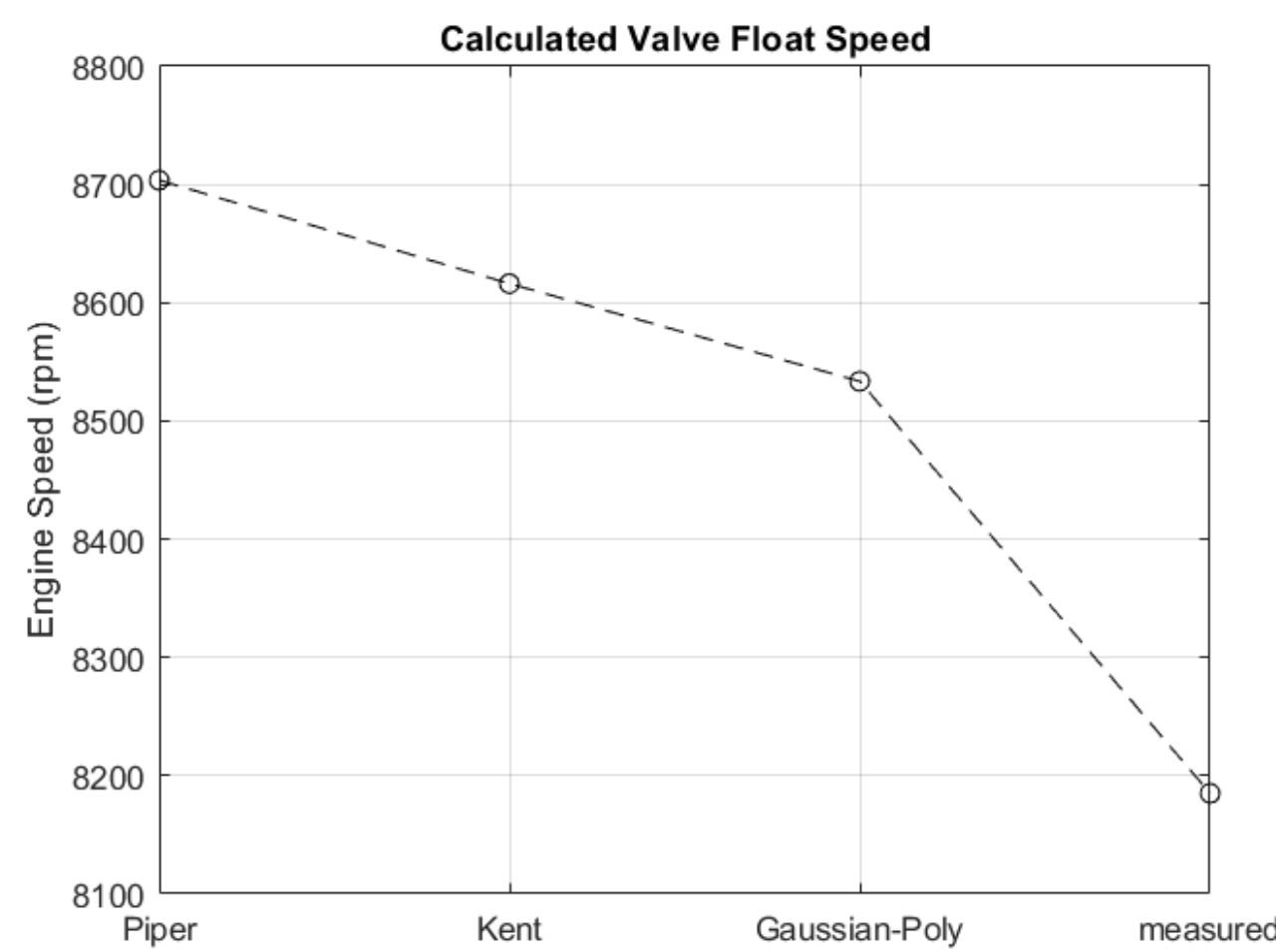
Valve acceleration from the study. The model fully converged at 0.1° matrix size. Interpolation type: spline (piecewise cubic).

Cam-to-Tappet Friction



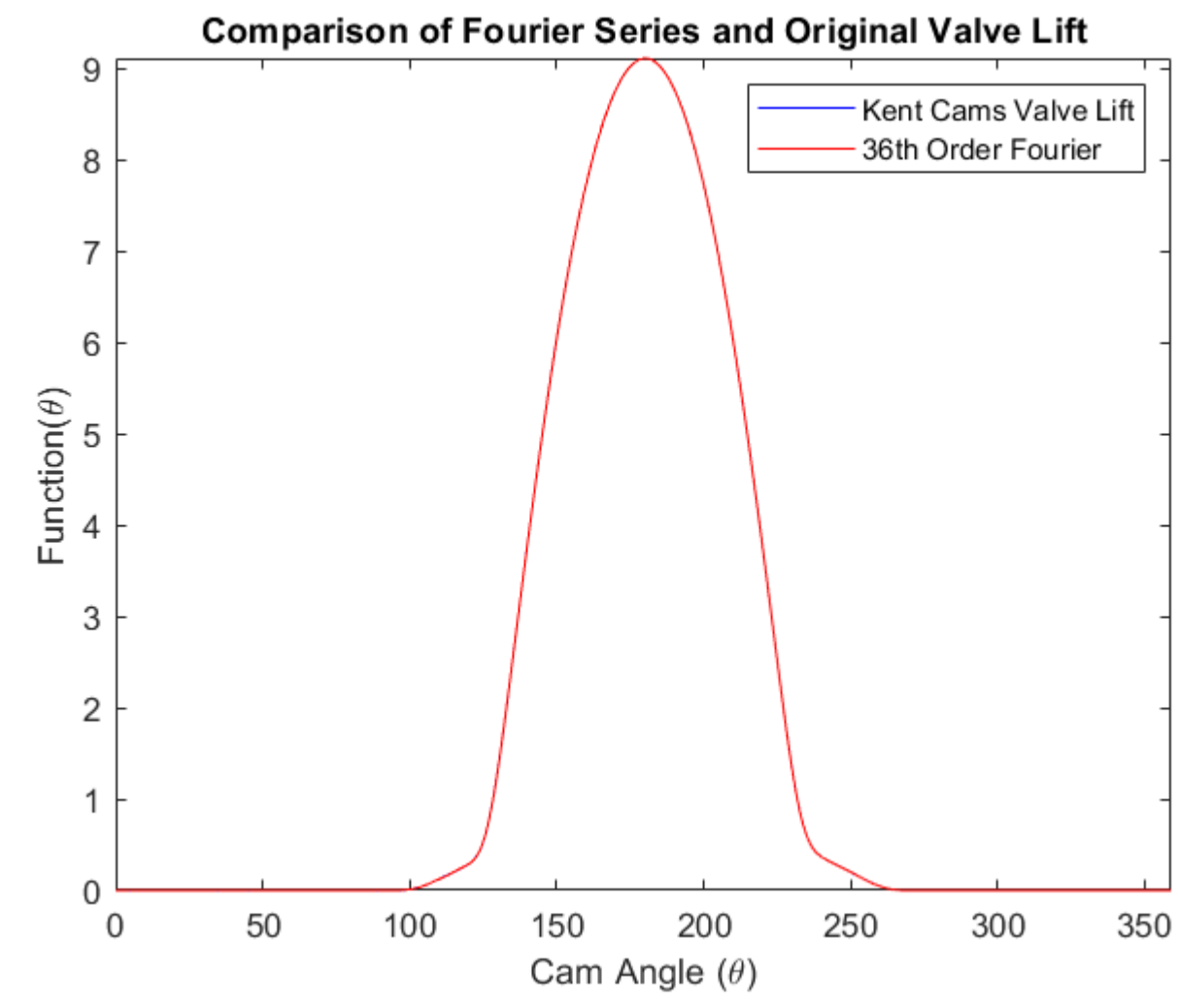
Valve spring stiffness (valve lift profile) dominates contact forces at low engine speed, with valvetrain inertia (acceleration profile) opposing this at higher speeds.

A total friction power loss of **1.3kW** (inlet) was found [4]. Valve float speeds were compared to commercial data, where an estimated **20% reduction** in power loss could be achieved by lowering the spring stiffness.



Valve float speed comparison between Piper Cams, Kent Cams, measured and improved (Gaussian-Polynomial),

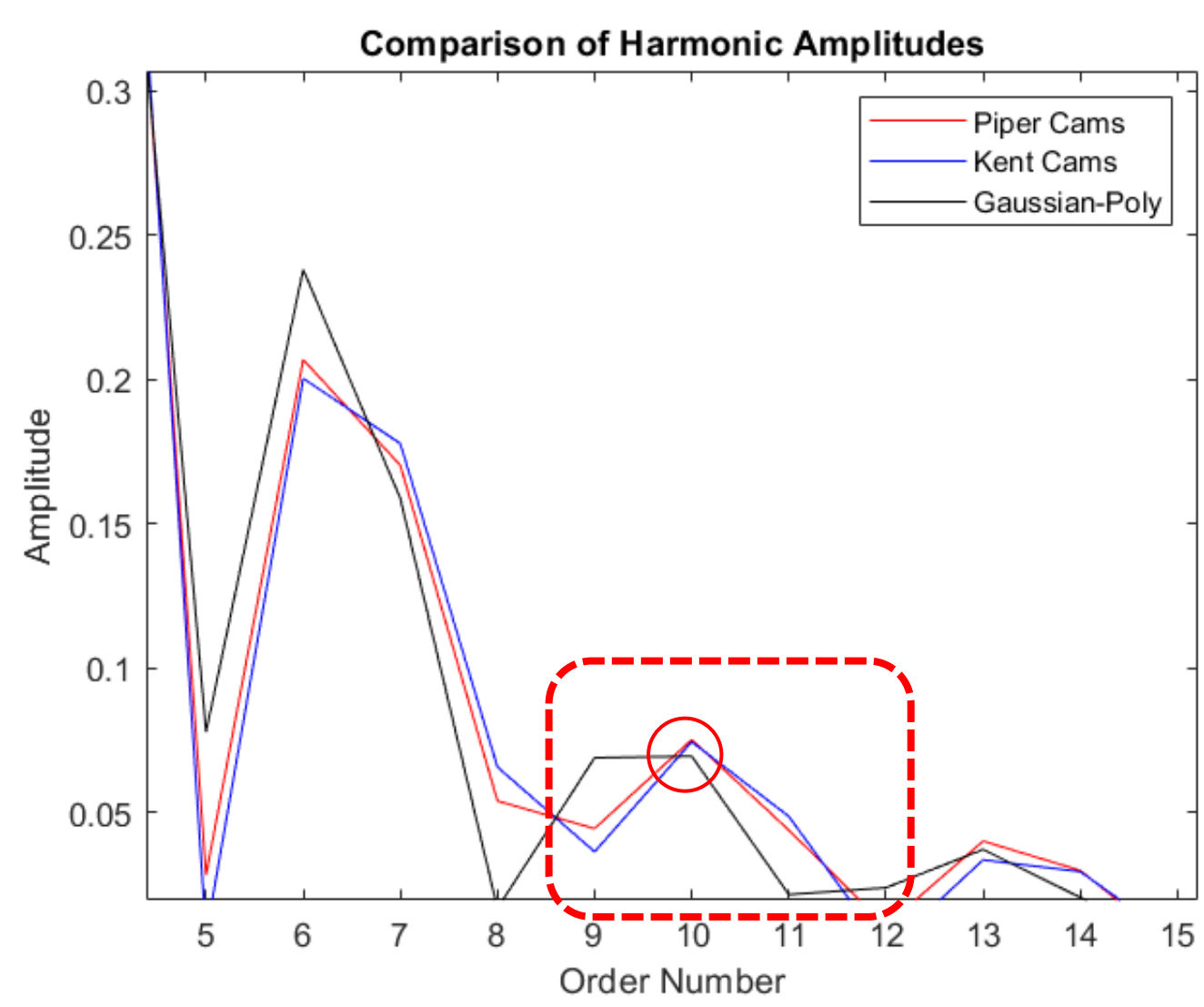
Harmonic Analysis



A Discrete Trigonometric Fourier Series (TFS) of valve displacement converged at 36th order, allowing an approximation of harmonic amplitudes.

$$\int_0^{2\pi} f(\theta) \, d\theta = \int_0^{2\pi} \left(a_0 + \sum_{n=1}^{36} a_n \cos(\theta) + b_n \sin(\theta) \right) d\theta$$

where a_n and b_n are Fourier coefficients of order n



Comparison of harmonic amplitudes for each valve lift profile (engine speed range highlighted). 10th order harmonic amplitude @ 6,396rpm (OEM valve spring).

The OEM spring surge frequency was calculated to be **533Hz** [5] . Target spring stiffness reduced this to **473Hz**, pushing the harmonic window for maximum engine speed (7,500rpm) from 9th to 8th order.

References

[1] Kent Cams (2020) 'Kent Cams Duratec Valve Lift'. Available at: <https://www.kentcams.com/>.

[2] PiperCams (2020) 'Piper Cams Duratec Valve Lift'. Available at: <https://pipercams.co.uk/camshafts-car>

[3] Sahu, L. K., Kedia, V. K. and Sahu, M. (2016) 'Design of Cam and Follower system using Basic and Synthetic curves : A Review', 3(2), pp. 362–372.

[4] Okarmus, M. M. and Keribar, R. (2015) 'Methodology for Predictive Friction Modelling in Direct-Acting Mechanical Bucket Valvetrain System'. doi: 10.4271/2015-01-0677.

[5] Schamel, A. R. et al. (1993) 'Modelling and Measurement Techniques for Valve Spring Dynamics in High Revving Internal Combustion Engines', (412).