

Assessing the Propensity for Valve Train Tick Noise

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ABSTRACT

Valve ticking noises within a cam actuated valve train can arise mysteriously. One valve train may produce valve ticking noises, while a second, geometrically similar valve train may perform more quietly. To better understand this phenomena, we examine in detail the prototypical motion of a valve driven by a rocker arm with cylindrical rocker pad. General features of a valve's motion through its guide, induced by a rocker arm with a cylindrical pad, are derived. From these general features of valve motion, guide contact points during lift events can be inferred, and as a result, detailed forces and moments acting on the valve may be derived. From this derivation of forces acting on the valve, a metric for assessing the propensity of a valve train to tick as a result of the valve stem impacting its guide is proposed. The proposed metric indicates how the likelihood of valve tick noise can be reduced through judicious choices for valve train geometries, clearances and surface finishes.

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INTRODUCTION

Exhaust and intake valves for a given engine are typically designed to ensure certain ratios of guided versus unsupported valve stem lengths at the hot and cold ends of the valve meet prescribed targets (see for example [3]). Other geometric design criteria specify a zero-lift valve stem height above a perpendicular to the valve stem that connects the valve stem axis to the rocker pivot. Typical values are 1/3 or 1/2 of maximum valve lift (see [2]). There are still additional design criteria that recommend valve guide to valve stem radial clearance.

To produce a high quality valve train, a focus on design geometry is of course important. However, geometry targets alone may not be sufficient to produce a quiet system. It is not only the valve train geometry, but also the forces driving noise generating collisions that must be assessed. The metric proposed in this paper assesses the interaction of geometry and valve tip forces by estimating the energy of valve stem to valve guide collision during lift events. Ultimately, the sound produced by such collisions must be gated by this input kinetic energy to the collision event. Our metric focuses on estimating this kinetic energy. The analysis below provides insight into how the energy-and hence the audible noise which is in effect a dissipation of this energy-may be reduced by valve and valve train design specifications.

Our development is specific to the case where the rocker that drives the valve has a cylindrical rocker pad, and is

oriented so that the contact point between valve and rocker pad is centered on the valve stem when the vector from rocker pivot to contact point is perpendicular to the valve guide axis. (This is common design practice.) [Figure 1](#) depicts a rocker arm and valve. The coordinate system we will use throughout assumes the y -axis is parallel to the valve guide axis. The positive y -direction indicates increasing valve lift. The positive x -axis is perpendicular to the axis of valve guide moving from the origin at the rocker pivot to the valve guide. Observe that this is a typical right-handed coordinate system, meaning that positive rotation about a vector directed out of the page (the z -axis) is counterclockwise. The unit vector $\vec{i}_t$ it is parallel to the plane of the valve tip and the x -axis. Angle α shown in the picture is measured from the position vector that locates the zero-lift contact point to the x -axis. Likewise, the angle η indicates an the angle from the zero-lift position vector to a position vector of a subsequent contact point. The angle $\eta - \alpha$ is therefore the polar angle of a contact point measured from the positive x -axis (which is directed left). Note that angles indicating a contact point above the x -axis (in the negative y -direction) are negative; those below the x -axis are positive.

$$\vec{v} = \vec{v}_{tr}^{(1)} + \vec{v}_r^{(1)} = \vec{v}_{tr}^{(2)} + \vec{v}_r^{(2)}. \quad (1)$$

Rewriting the last equation, we have

$$\vec{v}_r^{(2)} - \vec{v}_r^{(1)} = \vec{v}_{tr}^{(1)} - \vec{v}_{tr}^{(2)} \doteq \vec{v}^{(12)}. \quad (2)$$

Suppose that point $M^{(1)}(t)$ represents the point on Σ_1 that makes contact with surface Σ_2 at time t in reference frame S_1 . Suppose $M^{(2)}(t)$ is the corresponding point on Σ_2 that touches Σ_1 at time t in reference frame S_1 . At any given time $t = t_0$, $M^{(1)}(t_0) = M^{(2)}(t_0)$ (because the surfaces are in contact there). The middle equality in (2) shows that $v^{(12)}$ may be interpreted as the velocity an observer from surface Σ_2 in coordinate system S_2 sees as the direction and magnitude of motion for point $M^{(1)}(t_0)$. On the other hand, the left most equality in (2) indicates $v^{(12)}$ is also equal to the speed at which surface Σ_1 rubs or slides on surface Σ_2 .

The rocker arm shown in Figure 1 makes contact with the valve stem at zero lift at point M_0 . The rocker arm shaft axis passes through points D_i , $i = 1, 2$; this axis is perpendicular to the plane of the page. Surface Σ_2 is considered to be a narrow cross sectional slice of the rocker arm pad that is orthogonal to $\overline{D_1 D_2}$. The valve tip surface, labeled surface Σ_1 , is planar, and perpendicular to direction of valve movement. Define the positive x -axis of S_f to be the ray that is perpendicular to line $\overline{D_1 D_2}$ that passes through point M_0 , the initial contact point of contact between Σ_1 and Σ_2 at zero lift. The origin of S_f is D_i , the point where the x -axis intersects line $\overline{D_1 D_2}$. The angle α is that angle between the x -axis and the projection of this axis on the valve stem plane.

Physically, relative movement of two sliding surfaces cannot be directed in a way that causes one surface to puncture the other, the sliding velocity $v^{(12)}$ must lie in the tangent plane. Therefore, for all t

$$\langle \vec{n}_1, \vec{v}^{(12)} \rangle = 0. \quad (3)$$

Figure 2 shows that $\vec{v}_{tr}^{(2)} = r\omega\vec{u}$, where ω the angular rotation speed of Σ_2 , and r is the distance between the center of rotation (the origin) and the contact point on surface Σ_2 . This follows from the observation that the rocker arm is in pure rotation, and hence a fixed point on the rocker arm can only move in the u direction, and its distance from the origin is constant.¹ Here, $\vec{u} = -\vec{n}_1 \cos(\eta - \alpha) + \vec{i}_t \sin(\eta - \alpha)$. (See Figure 2.)

On the other hand, $\vec{v}_{tr}^{(1)}$ has only a component in the $\vec{n}_1$ direction, since the valve stem translates without rotation in a direction normal to its valve tip surface. (Recall that $\vec{v}_{tr}^{(1)}$ includes no sliding velocity along the surface of the valve tip.) It follows that²

$$\begin{aligned} \langle \vec{v}^{(12)}, \vec{i}_t \rangle &= \langle \vec{v}_{tr}^{(1)} - \vec{v}_{tr}^{(2)}, \vec{i}_t \rangle \\ &= [r\omega \sin(\eta - \alpha)], \end{aligned} \quad (4)$$

Because the valve tip is planar and does not rotate, $\vec{n}_1$ and $\vec{i}_t$ are constant unit vectors. If $r(\eta(t) - \alpha)$ is the distance from the rocker pivot to the point of contact at time t , it follows that the sliding velocity is

$$\begin{aligned} \vec{v}^{(12)} &= \vec{i}_t [r\omega \sin(\eta - \alpha)] \\ \Rightarrow v^{(12)} &\approx r\dot{\eta} \sin(\eta - \alpha). \end{aligned} \quad (5)$$

Here, we have used the approximation that $\dot{\eta}$ is approximately equal to rocker arm rotation speed ω .

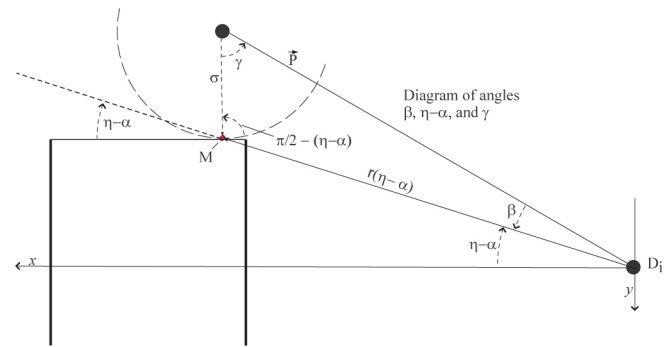


Figure 3. The radial distance r from the rocker arm pivot at the origin of the coordinate system is specified as a function of $\eta - \alpha$, the angular offset from the positive x -axis. An intermediate point for a non-zero angle η is shown in the second diagram. Angles γ and β are used in the proof of Lemma 1, and in general are functions of angle η .

THE CONTACT POINT PATH

Determining the contact point relative to the central axis of the valve stem facilitates the calculation of torques acting on the valve.

Lemma 1 Suppose that angle α represents the angle between the positive x -axis and the zero-lift contact point position vector connecting the rocker pivot and a point on the valve tip surface c_0 . Suppose the rocker arm pad is

¹Note: $\vec{v}_{tr}^{(2)}$ is defined as the velocity of a fixed point on surface Σ_2 . The velocity $\vec{v}_{tr}^{(2)}$ does not include any velocity contribution due to sliding motion along the surface of Σ_2 . Note that ω , the rotational speed of the rocker arm, is approximately equal to $\dot{\eta}$.

²We use the notation that $\langle \vec{a}, \vec{b} \rangle$ represents the dot product of two vectors $\vec{a}$ and $\vec{b}$.