

TABLE 14-5 Force and Moment Balance State of an 8-Cylinder, Vee Engine with a 0, 90, 270, 180° Crankshaft, and $z_1 = 1, z_2 = 2, z_3 = 3, z_4 = 4$

Primary forces :	$\sum_{i=1}^n \sin \phi_i = 0$	$\sum_{i=1}^n \cos \phi_i = 0$
Secondary forces :	$\sum_{i=1}^n \sin 2\phi_i = 0$	$\sum_{i=1}^n \cos 2\phi_i = 0$
Fourth harmonic forces :	$\sum_{i=1}^n \sin 4\phi_i = 0$	$\sum_{i=1}^n \cos 4\phi_i = 8$
Sixth harmonic forces :	$\sum_{i=1}^n \sin 6\phi_i = 0$	$\sum_{i=1}^n \cos 6\phi_i = 0$
Primary moments :	$\sum_{i=1}^n z_i \sin \phi_i = -4$	$\sum_{i=1}^n z_i \cos \phi_i = -2$
Secondary moments :	$\sum_{i=1}^n z_i \sin 2\phi_i = 0$	$\sum_{i=1}^n z_i \cos 2\phi_i = 0$
Fourth harmonic moments :	$\sum_{i=1}^n z_i \sin 4\phi_i = 0$	$\sum_{i=1}^n z_i \cos 4\phi_i = 28$
Sixth harmonic moments :	$\sum_{i=1}^n z_i \sin 6\phi_i = 0$	$\sum_{i=1}^n z_i \cos 6\phi_i = 0$

Any vee cylinder configuration may have one or more desirable vee angles which will give both even firing and acceptable inertia balance. However, vee engines of fewer than twelve cylinders will not be completely balanced by means of their crankshaft configuration. The desirable vee angles will typically be an integer multiple (including one) or submultiple of the optimum delta phase angle as defined in equations 14.8 (pp. 652 and 654) for that engine. Ninety degrees is the optimum vee angle (2γ) for an eight-cylinder vee engine. To see the results for this vee-eight engine configuration, run program ENGINE and select the vee eight from the *Examples* pull-down menu. See Appendix A for instructions on the use of the program.

14.8 OPPOSED ENGINE CONFIGURATIONS

An opposed engine is essentially a vee engine with a 180° vee angle. The advantage, particularly with a small number of cylinders such as two or four, is the relatively good balance condition possible. A four-stroke opposed twin* with 0, 180° crank has even firing plus primary force balance, though the primary moment and all higher harmonics of force and moment are nonzero. A four-stroke, opposed four-cylinder engine (flat four) with a 0, 180, 180, 0°, four-throw crank has primary force balance but must fire its cylinders in pairs, so its firing pattern looks like a twin. A four-stroke flat four with a two-

* As in the BMW R-series motorcycles.