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**Engine Cooling Fan Structural Analysis**

**Foreword**—This SAE Recommended Practice is intended as a guide toward standard practice but may be subject to frequent change to keep pace with experience and technical advances, and this should be kept in mind when considering its use.

1. **Scope**—Three levels of fan structural analysis are included in this practice:

1. Initial Structural Integrity
2. In-vehicle Testing
3. Durability Test Methods

The Initial Structural Integrity section describes analytical and test methods used to predict potential resonance and, therefore, possible fatigue accumulation.

The In-vehicle (or machine) section enumerates the general procedure used to conduct a fan strain gage test. Various considerations that may affect the outcome of strain gage data have been described for the user of this procedure to adapt/discard depending on the particular application.

The Durability Test Methods section describes the detailed test procedures that may be used depending on type of fan, equipment availability, and end objective.

Each of the previous levels builds upon information derived from the previous level. Engineering judgment is required as to the applicability of each level to a different vehicle environment or a new fan design.

This SAE Recommended Practice is applicable to medium and heavy-duty trucks, buses, construction equipment, industrial, and agricultural equipment. It does not necessarily include passenger cars and light trucks.

1.1 **Purpose**—The purpose of this document is to identify the general methodology for the structural analysis of engine cooling fans, and to provide expanded information on subset practices within the general methodology, such that a user of this practice can adapt specific subsets related to a vehicle<sup>1</sup> class.

1. The term "vehicle" as used in this practice is defined as an all-inclusive term.

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**2. References**

**2.1 Applicable Publications**—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

- SAE J1099—Technical Report on Low Cycle Fatigue Properties Ferrous and Non-Ferrous of Materials
- SAE J1116—Categories of Off-Road Self-Propelled Work Machines
- SAE J1234—Specification Definitions—Off-Road Work Machines
- SAE J1474—Heavy-Duty Nonmetallic Engine Cooling Fans—Material, Manufacturing and Test Considerations
- SAE J/ISO 6165—Earthmoving machines—Basic Types—Vocabulary

**3. Initial Structural Integrity**

**3.1 Scope**—It is necessary to identify and attempt to evaluate the characteristics of an application which can have an effect on fan durability. Failures almost always occur in fatigue, so careful attention should be paid to avoid resonance or forced vibration of the fan. This section considers vibrational inputs, fan natural frequencies, and operating speed as part of the initial structural integrity analysis. A fan application fact sheet (Figure 1) is recommended as a form to communicate between user and fan supplier.

3.1.1 A resonant condition may occur when the natural frequencies of the fan as determined from 3.3 is coincident with either of the vibrational input frequencies or their harmonics, as calculated in 3.2.

Therefore, it is desirable to separate these frequencies, including the upper and lower harmonics, whenever possible. In addition, torsional vibrations, auxiliary equipment, driveline vibrations, etc., may cause vibratory inputs to the fan which cannot be predicted in equation form.

**3.2 Vibrational Inputs**

3.2.1 Without verification by in-vehicle testing, the potential critical speeds and frequencies that can affect the fan can only be predicted. Two potential frequencies of vibration are the harmonics of the piston firing frequency Equation 1 and the harmonics of the fan rotational frequency associated with obstructions that cause a non-uniform or pulsating flow as the fan rotates (Equation 2).

$$\text{Piston Firing Frequency} = \frac{(\text{No. of Cylinders})(\text{Engine rpm})}{(30)(\text{No. of Cycles})} \quad (\text{Eq. 1})$$

where:

Number of cycles refers to two or four stroke engine

$$\text{Fan Rotational Harmonic Frequencies} = \frac{(n)(\text{Fan RPM})}{60} \quad (\text{Eq. 2})$$

**PART ONE – FAN USER INFORMATION**

Customer: \_\_\_\_\_  
 Location: \_\_\_\_\_  
 Contact: \_\_\_\_\_  
 Phone Number: \_\_\_\_\_  
**Performance Required** Speed \_\_\_\_\_ revolutions/minute  
 Volumetric Flow at \_\_\_\_\_ Static Resistance Pressure \_\_\_\_\_  
 Air Density: \_\_\_\_\_ Estimated Fan Power: \_\_\_\_\_

**Limitations**

Maximum Diameter \_\_\_\_\_ Over-speed: \_\_\_\_\_  
 Maximum Projected Width \_\_\_\_\_ Maximum Fan Power: \_\_\_\_\_

**Other**

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Application Description**

Model Number \_\_\_\_\_  
 Engine: \_\_\_\_\_  
 Rated Power: \_\_\_\_\_ at Speed: \_\_\_\_\_  
 Drive Type: \_\_\_\_\_  
 Fan Drive Ratio: \_\_\_\_\_  
 Fan Mounting Location: \_\_\_\_\_  
 Fan Rotation: \_\_\_\_\_  
 Pilot and Bolt Circle: \_\_\_\_\_  
 Maximum Run-out: \_\_\_\_\_  
 Belt Tension: \_\_\_\_\_

**System**

Shroud: \_\_\_\_\_ Diameter: \_\_\_\_\_ Type \_\_\_\_\_  
 Fan Position: \_\_\_\_\_  
 Clearance to Obstructions: Front: \_\_\_\_\_ Rear: \_\_\_\_\_

**Required Testing**

\_\_\_\_\_ Airflow \_\_\_\_\_ Spin Pit \_\_\_\_\_  
 \_\_\_\_\_ Shaker Scan \_\_\_\_\_ Strain Gage \_\_\_\_\_  
 \_\_\_\_\_ Endurance ("Bench Test") \_\_\_\_\_ Other: \_\_\_\_\_

**PART TWO – FAN SUPPLIER INFORMATION**

Manufacturer: \_\_\_\_\_  
 Location: \_\_\_\_\_  
 Contact: \_\_\_\_\_  
 Phone Number: \_\_\_\_\_

**Proposal**

Manufacturer's Part Number: \_\_\_\_\_  
 Drawing Attached: \_\_\_\_\_  
 Fan Weight \_\_\_\_\_ Inertia \_\_\_\_\_  
 Maximum Fan Unbalance \_\_\_\_\_  
 Other \_\_\_\_\_

**Test Results Attached**

\_\_\_\_\_ Airflow Performance \_\_\_\_\_  
 \_\_\_\_\_ Shaker Scan \_\_\_\_\_  
 \_\_\_\_\_ Spin Pit Burst Speed (Actual/Calculated) \_\_\_\_\_  
 \_\_\_\_\_ Strain Gage Data \_\_\_\_\_  
 \_\_\_\_\_ Material Properties \_\_\_\_\_  
 \_\_\_\_\_ Endurance ("Bench Test") \_\_\_\_\_  
 \_\_\_\_\_ Other: \_\_\_\_\_

FIGURE 1—FAN APPLICATION FACT SHEET

### 3.3 Fan Natural Frequencies

3.3.1 The resonant frequencies and location of the node lines of the fan should be measured for each mode of vibration. This can be done by using a shaker table, accelerometers, strain gages, or by observation. The resonant frequencies may be for both rectilinear and torsional modes of vibration. Each resonant frequency of a fan can be affected by the following:

- a. The shape of the fan mounting surface, which may affect the relative spring constant of the system and should be duplicated as closely as possible.
- b. The torque of the mounting bolts may also affect the relative spring constant.
- c. Dimensional variations from fan to fan, including material tolerances, may affect both the relative spring constant and the vibrating mass.

When using means other than the actual installation for driving the vibrating mass, caution should be exercised with the excitation level as the natural resonant frequencies can be masked by the high excitation levels of an over driven forced vibration.

3.3.2 The maximum stress may not occur at the resonant frequency. It may occur at a beat frequency between the resonant frequencies of two different modes of vibration, i.e., a combination of rectilinear and torsional excitation.

3.3.3 Finite element analysis methods may be used as a supplement to the previous test methods. Mode shapes and frequencies, and relative stress gradients can be numerically predicted and compared to vehicle vibrational inputs.

### 3.4 Operating Speed

3.4.1 It is desirable to keep the fan operating speed as low as possible to minimize stresses due to centrifugal force.

### 3.5 Log Sheet

3.5.1 The fan user and supplier may wish to establish a fan application fact sheet. This can be used to identify design parameters that affect fan performance for their particular application and to record the basic fan characteristics. It must be remembered, however, that one cannot anticipate all of the factors that will affect fan durability while early in the design stage. No itemized list will be all-inclusive, and no algorithm is possible. A sample fact sheet is provided as Figure 1. Users should feel free to modify it as mutually desired.

## 4. In-vehicle Test

4.1 **Scope**—In-vehicle tests can be used to complement the Initial Structural Integrity section of this document because the forces on a fan are determined by a combination of the fan's operating environment and the engine/vehicle operational duty cycle conditions. A fan designed for a specific vehicle application and having satisfactory structural strength in its intended application may have unsatisfactory durability in a different application. The following sections will aid in the selection of a suitable test vehicle, in the preparation and instrumentation of the vehicle for test, and in conducting the actual test.

**4.2 Test Vehicle Selection**—This subsection considers the kinds of standard and optional vehicle equipment which can impose forces, vibrations, and frequencies on the subject fan. The vehicle equipment environment influences the fan by three different methods. Equipment obstructions ahead of, behind, and around the fan disturb the air flow passing through the fan. This air flow disturbance imposes forces and vibrations on the fan. The engine and other equipment are sources of mechanical vibrations. These vibrations can propagate and be transmitted to the fan through its mounting attachment. The fan drive that determines the plane-of-rotation, the center-of-rotation, and the rotational speed directly affects inertial forces and vibrations in the fan. Consideration of these factors will permit the tester to specify the appropriate optional equipment for the test vehicle.

**4.2.1 PACKAGE OBSTRUCTIONS**—Equipment located in the near vicinity of the fan that restricts and obstructs the fan air flow.

**4.2.1.1 Radiator Core**—Consider the variation in air flow restriction due to optional radiator cores with a different number of tube rows, fin densities, and fin designs. Radiator tanks, side structures, and cross-reinforcing rods can be significant obstructions if the fan partially “sweeps” any of these items.

**4.2.1.2 Heat Exchanger Core**—Any finned core located ahead or behind the fan will restrict air flow. Examples are air conditioning condenser and coolers for engine lubricating oil, power steering fluid, automatic transmission fluid, and hydraulic PTO fluid, and charge air coolers.

**4.2.1.3 Shroud**—Optional fan shroud or hand guards.

**4.2.1.4 Radiator Shutters**—Mounting location (in front or behind radiator) and type (modulating or full open-full closed).

**4.2.1.5 Winter Front**—Optional grille mounted winter fronts.

**4.2.1.6 Blockage**—Frame member or body sheet metal obstructions, belt pulleys and crankshaft damper can present blockages in when in proximity to the fan.

**4.2.1.7 PTO Shafts**—Front crankshaft driven power take-off shaft.

**4.2.1.8 Deflector**—Optional fan blast deflector.

**4.2.2 VIBRATION SOURCES**—Equipment that generates mechanical vibrations. Because these equipment items are commonly located in the immediate vicinity of the fan, they also cause fan air flow obstruction effects.

**4.2.2.1 Engine**—Design parameters and/or data permit the tester to consider engine vibration magnitudes and fundamental forcing frequencies.

**4.2.2.1.1 Type**—Gasoline or diesel, two-stroke cycle or four-stroke cycle, number of cylinders, in-line or Vee, turbocharged or naturally aspirated, uniform or uneven cylinder firing interval.

**4.2.2.1.2 Size**—Displacement, bore, stroke, and power rating.

**4.2.2.1.3 Crankshaft Damper**—Determine if a damper is provided, and location of fan drive pulley with respect to damper (is fan driven from crank or damper inertia member?).

**4.2.2.1.4 Speed**—Governed or rated engine speed; fast idle or sub-idle.

**4.2.2.1.5 Vibration Data**—Review any available vibration test data for magnitudes and frequency. Crankshaft torsional data is important.

- 4.2.2.2 *Accessories*—Power steering pump, air brake compressor, air conditioning compressor, alternator, emissions air pump, vacuum brake pump, and hydraulic brake booster pump.
- 4.2.2.3 *Driveline*—Optional sizes, lengths, and types (one-piece or two-piece).
- 4.2.3 FAN DRIVE—The drive ratio and clutch, if used, control fan rotational speed. Additionally, the drive acts as the path to transmit mechanical vibration to the fan.
- 4.2.3.1 *Type*—Gear or belt, fixed or clutch (on-off, modulated engagement or viscous).
- 4.2.3.2 *Ratio*—Fan speed to engine speed ratio.
- 4.2.3.3 *Position*—Fan mounting position on end of crankshaft, on water pump shaft, or remote mounted fan spindle.
- 4.2.3.4 *Fan Mounting*—Fan mounting surface or spacer configuration.
- 4.3 **Instrumentation**—This section considers the preparation and instrumentation of the subject fan and the selected test vehicle.
- 4.3.1 STRAIN GAGE LOCATION—It is important that strain gages are placed at all of the highly stressed locations on the subject fan. Several methods exist for gage location. The best procedure is to employ multiple methods of gage location and to use a generous number of gages. This will reduce the risk that a highly stressed location has been overlooked. The fully strained gaged fan becomes in effect a “master fan.” It should be handled carefully during the in-vehicle test and should be safely stored after test completion. Retention of the “master fan” will allow for its use in future in-vehicle tests or to correlate bench durability tests.
- 4.3.1.1 *Brittle Lacquer*—Strain gage locations are determined by crack patterns developed in the brittle lacquer coating. The brittle coating can be patterned in the test vehicle and/or on a bench test stand. The bench procedure can use rotational and/or axial excitation.
- 4.3.1.2 *Judgment*—Gage locations determined by past experience with similar fan designs or by analytical analysis of the subject fan design. Contact fan supplier for gage location information.
- 4.3.1.3 *Modal Analysis*—Gage locations are along the node lines of the principal modes that are expected to receive the largest amounts of vibrational energy.
- 4.3.1.4 *Finite Element*—Gage locations are determined from the computer analysis of a finite element model.
- 4.3.1.5 *Photoelastic*—Gage locations are determined from the bi-refrangent pattern in a photoelastic coating on the subject fan.
- 4.3.1.6 *Failures*—Gage locations determined by the fatigue crack pattern in a failed fan.
- 4.3.2 RECORDED DATA—Suitable instrumentation is required to record engine speed, fan speed except when fan is solidly driven on the crankshaft, and strain gage output magnitude and frequency. For a viscous drive, sensor air temperature and clutch housing temperature may be recorded. For a plastic fan, (non-metallic) the adjacent air temperature, plastic material temperature and temperature of fan mount material in contact with fan are required. (See SAE J1474 for more information on testing non-metallic fans.)

4.3.3 VEHICLES MEASUREMENTS—Specific measurements may be made on the selected test vehicle so that the following factors will be known.

4.3.3.1 *Fan Drive Break-in*—New friction disks in fan drives may require a break-in.

4.3.3.2 *V-Belts*—Adjust belt tension on all accessory drives including the fan drive to the specified maximum. New V-belts may require “break in.”

4.3.3.3 *Fan Mounting*—Record the axial runout of the fan drive mounting surface and the radial runout of the fan drive pilot.

4.3.3.4 *Fan to Shroud*—Record radial tip clearances. Record the axial position of fan in fan shroud. Record the fan to radiator clearance.

4.4 **Vehicle Test**—The intent of the in-vehicle fan test is to record fan strains while vehicle operational duty cycle conditions and the fan operating environment are varied in a systematic way. This will determine the combination of factors that cause the highest fan strains.

4.4.1 VIBRATION SOURCES—Determine the effect on fan strains for different vibration input conditions.

4.4.1.1 *Engine Load*—Test with engine at full load, partial load, and no load conditions.

4.4.1.2 *Engine Speed*—Test condition of maximum speed (governed speed or rated speed and a specific over speed) and speed transients due to automatic or manual transmission shifting. Test engine start-up, shut-down, idle, and specific below idle speed conditions. Scan the engine operating speed range in a continuous sweep mode in each transmission gear position to identify fan resonances and maximum fan strain amplitudes.

4.4.1.3 *Accessories*—Test the effect of the on-off duty cycle of various accessories.

4.4.1.4 *Fan Clutch*—Determine the effect of the fan clutch operating modes. For nonviscous clutches—locked operation and on-off transients. For viscous clutches—disengaged, fully engaged, and mechanically locked operation.

4.4.1.5 *Fan Drive*—Test with fan mounting components (water pump, spacer, fan drive) that produce the maximum allowable radial and axial runout.

4.4.1.6 *V-Belts*—Test with both a “loose” belt tension condition and with an over-tightened belt tension condition. This is applicable to the fan drive belts and to all accessories.

4.4.2 OBSTRUCTIONS—Determine the effect on fan strains caused by obstruction changes.

4.4.2.1 *Accessories*—Selectively remove individual accessories to determine their obstruction effect on fan strains.

4.4.2.2 *Radiator Core*—Determine effects of change in air flow restriction caused by an optional core. Simulate the restriction increase due to core clogging in service.

4.4.2.3 *Radiator Shutters*—Effects of shutters open, closed, and partially open if the modulating shutter type is used.

4.4.2.4 *Winter Front*—Test the effect on fan strains caused by the use of winter fronts or cardboard.

- 4.4.2.5 *Shroud*—Test for the effects of an optional fan shroud.
- 4.4.2.6 *Heat Exchanger Core*—Test for the obstruction effect on fan strains by selectively removing optional heat exchanger cores.
- 4.4.3 IN-SERVICE EVALUATION—Simulate special conditions occurring during typical vehicle operation.
- 4.4.3.1 *Shock*—Effects on road, cargo loading, or auxiliary equipment caused shock inputs.
- 4.4.3.2 *Water Splash or Fording*—Can be significant source of low cycle or non-fatigue fan destructive stresses.
- 4.4.3.3 *Dirt Build-Up*—Can cause vibration due to rotating imbalance of fan.
- 4.5 **Analysis**—The strain data gathered during in-vehicle testing must be analyzed to be useful to the engineer. SAE J1099 provides information that is useful in the analysis of service load and/or strain data. It also contains a list of references that have proven useful in the analysis of fatigue data.

## 5. **Durability Test Methods**

- 5.1 **Scope**—Durability tests can be used to complement in-vehicle strain gage testing. Testing can also evaluate areas inaccessible to conventional strain gage measurements. Durability testing, with the ability to control and increase strain levels, can demonstrate design factors at loads greater than anticipated service. Bench testing allows evaluation of the fan at a greatly accelerated rate compared to the rate of most in-vehicle testing.
- 5.2 **Methods**—A variety of bench tests are used to evaluate fans. It is difficult for any one test to accurately reproduce every operating characteristic. The user must select the method(s) that satisfy his/her durability criteria. Since it is accepted that fan durability considerations are associated with fatigue, the methods outlined are generally designed to evaluate endurance characteristics.
- 5.2.1 NONROTATIONAL RESONANT TEST—The test fan is mounted at the pilot and bolt circle and loaded axially through the range of amplitude and frequencies of interest. This method may not accurately reproduce all modal conditions and will not include strains produced by centrifugal loading.
- 5.2.1.1 *Equipment (Shaker Table)*—The vibrator should be capable of accepting various fan mounting arrangements with normal input loading from 50 to 500 N and a frequency range of 25 to 500 Hz.
- 5.2.1.2 *Instrumentation*—A method of monitoring frequency and strain amplitudes that will accurately relate the test conditions to the in-vehicle conditions is required. Additionally, the use of a strobe light and frequency analysis may aid in the test evaluation.
- 5.2.1.3 *Procedure*—The fan mounting should be a close representation of that found in the vehicle (that is, hub, spacer, clutch, etc.). This assembly is mounted to the driving member of the loading source. If the test assembly must be suspended, use caution to minimize the frequency effects on the test results.
- 5.2.1.4 *Durability Test*—Mount the “master fan” used in the vehicle analysis and set the test stand to simulate the frequency mode of vibrating and the highest dynamic strain level observed during the vehicle test. Because the minor variations of physical conditions of nominally identical parts can cause small changes in resonant frequencies, each test fan should be gaged to insure operation at the required test condition. Replace the “master fan” with the test fan and adjust frequency if necessary to maintain peak resonance. Other than frequency, all test conditions must remain as set up with the master fan. Monitor equipment to insure that conditions remain stable during testing. Strain levels higher than anticipated can also be tested.

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- 5.2.2 **RAPID CYCLE TEST**—This test rotates the fan from zero or a low speed to some predetermined maximum speed and back again. The test has limited applications, but can be used for flex fans and to simulate some unusual in-vehicle situations primarily encountered with viscous drives and other add-on clutches.
- 5.2.2.1 *Equipment*—Test stand can be driven with an electric motor and should be capable of adjusting the acceleration, maximum speed, deceleration, and dwell time. Test stand power requirements may be substantially higher than the in-vehicle rating of the fan.
- 5.2.2.2 *Instrumentation*—A method of monitoring frequency and strain amplitudes that will accurately relate the test conditions to the in-vehicle conditions is required. The use of a strobe light and frequency analyzer may aid in the test evaluation. Additionally, methods of measuring speed and acceleration/deceleration will be required.
- 5.2.2.3 *Procedure*—The fan mounting should be a close representation of that found in the vehicle (that is, hub, spacer, clutch, etc.). This assembly is mounted to the driveshaft. Use caution to minimize the frequency effects of the slip ring or adapters on the test results.
- 5.2.2.4 *Durability Test*—Mount the “master fan” used in the vehicle analysis and adjust the test stand to duplicate both frequencies and highest strain levels observed during the vehicle test. Replace the “master fan” with a test fan before testing. Monitor acceleration, speeds, and deceleration to insure that conditions remain stable during the test.
- 5.2.3 **TORSIONALLY LOADED ROTATING TEST**—This test rotates the fan at some constant operating speed while applying a torsional vibration to the driveshaft. The test can accurately duplicate centrifugal loads while accumulating stress cycles very rapidly. Durability of the test equipment can be a problem.
- 5.2.3.1 *Equipment*—The test stand can be driven with an electric motor. The fan shaft may be driven through “U” joints or off-center pulleys or other methods to produce the torsional loads. Hydraulically driven, torsional actuators are also available with load and frequency capabilities suitable for fan testing. Speed and power capabilities should reproduce all possible vehicle conditions. It should be noted the “U” joint excited tests may be limited to lower fan speeds because of joint durability problems.
- 5.2.3.2 *Instrumentation*—A method of measuring speed, frequency, and strain amplitude that will accurately relate the test conditions to the in-vehicle conditions is required.
- 5.2.3.3 *Procedure*—The fan mounting should be a close representation of that found in the vehicle (that is, hub, spacer, clutch, etc.). This assembly is mounted to the driveshaft. Use caution to minimize the frequency effects of the slip ring or adapters on the test results.
- 5.2.3.4 *Durability Test*—Mount the “master fan” used in the vehicle analysis and set the test stand to simulate the frequency and speed at the highest strain levels observed during the in-vehicle test. Because the minor variations of physical conditions of nominally identical parts can cause small changes in resonant frequencies, each test fan should be gaged to insure operation at the required test conditions. Normally one to four gages are sufficient. Replace the “master fan” with a test fan and adjust the speed, if necessary, to maintain peak resonance. All other conditions must remain as established with the “master fan.” Monitor equipment to maintain stability during testing. Strain levels higher than anticipated service can also be tested.
- 5.2.4 **OBSTRUCTION LOADED ROTATING TEST**—This test rotates the fan at some constant operating speed while applying air loaded vibrations by placing obstructions in front and/or behind the fan. The test can accurately duplicate centrifugal loads while accumulating stress cycles very rapidly.