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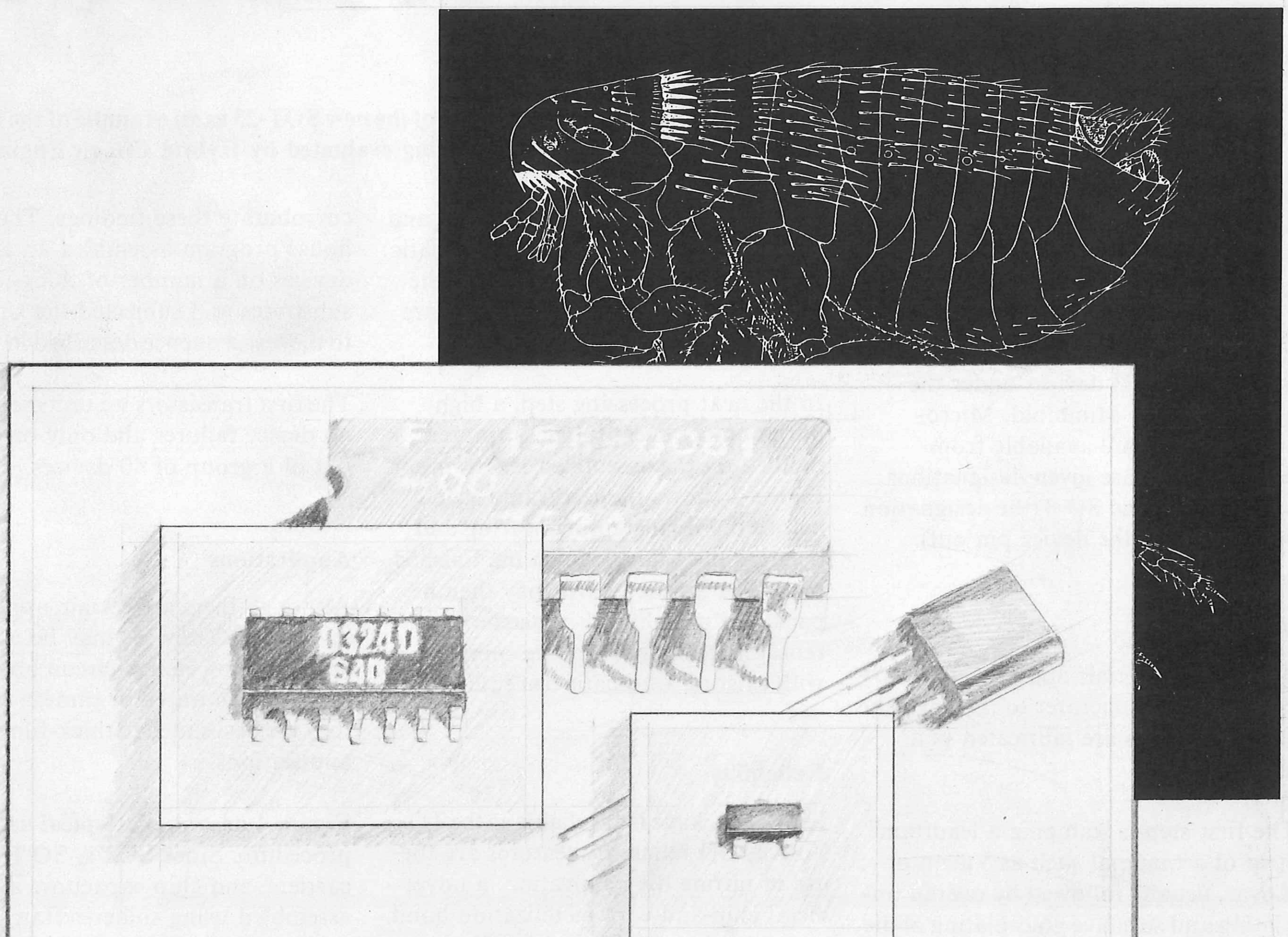
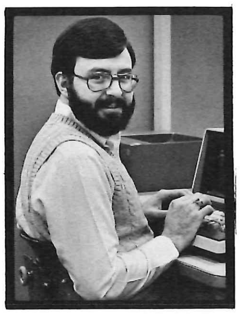
NEW TRENDS IN HYBRID TECHNOLOGY

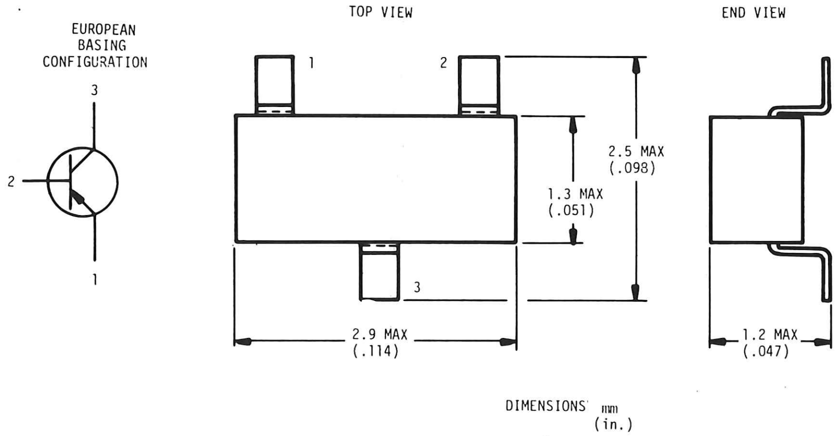


NEW TRENDS IN HYBRID TECHNOLOGY

Hybrid Circuit Engineering is evaluating two new packaging concepts. One is a leadless, hermetic chip carrier, and the other is a family of microminiature transistors and IC's. Both appear to be viable approaches to active-element hybrid circuit design, and provide an alternative to the various "naked-chip" hybrid techniques.



Peter White, Hybrid Circuits Engineering, ext. 6098.



The diagram details the dimensions of the new SOT-23 as an example of the family of microminiature transistors now being evaluated by Hybrid Circuit Engineering.

SO DEVICES

New microminiatrue packaged transistors and diodes are available from European vendors (Amperex, Seimens, and Farrante) under the designation SOT-23 and from Texas Instruments and Motorola under the JEDEC designation TO-236. Nippon Electric Co., the main Asian source, markets SOT-23 devices under the brand name of Minimold. Microminature IC's are available from Amperex and are given designations such as SO-6 and SO-8 (the designation depends upon the device pin out).

Fabrication

Although materials and processes vary from one manufacturer to the next, the various devices are fabricated in a similiar way.

The first step is stamping a leadframe strip of a material such as Vacon or Kovar, usually followed by overall tin-plating and selective gold-plating of die and wire-bond areas.

The chips are eutectically mounted and wire-bonded using standard automatic techniques. Pad dimensions limit the chip area to approximately 30 square mils.

In the next processing step, a high-purity epoxy encapsulant is tranfer molded on the assembled leadframe. Figure 2 shows the leadframe strip before the final step of shearing and bending the leads to form the finished part. The finished parts may then be packaged pre-aligned in plastic or reusable steel tubes that are compatible with existing automatic test equipment.

Reliability

The SO package is as reliable as the TO-92. Key SO reliability features are the use of nitride die passivation, a novel metal chip-and-wire metalization bond system and an ultrapure, moisture-resistant epoxy molding compound.

Comparison of environmental test data from independent sources suggests excellent reliability. In-house test data corroborate these findings. The in-house program assembled an array of devices on a number of thick-film substrates and subjected the substrates to the test sequence described in figure 3.

The first transistors we tested exhibited no device failures and only one defect out of a group of 40 devices.

Applications

Although there are certain applications in which SO devices may be used to advantage on etched-circuit boards (for example, in watch or camera circuits), they are best suited to thick-film ceramic applications.

Figure 4 describes a typical assembly procedure. Since SOT's, SO IC's, chip carriers, and chip capacitors are all assembled using solder-reflow, it is possible to assemble any combination of these devices in a single operation. Figure 5 shows such a hybrid. This hybrid was designed to demonstrate the compatibility of these devices, as well as the design flexibility afforded by their use.

Design flexibility will be further enhanced as SO IC's become more available. At present, Amperex-Phillips offers 17 different circuits including single, dual and quad op-amps (both general and high performance), timers, FM detectors, voltage followers and double-balanced modulators.

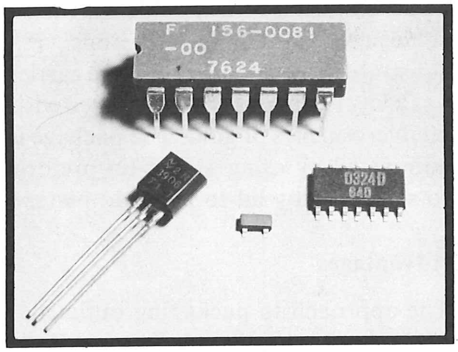


Figure 1. At the top is a standard 14-pin DIP (dual-in-line package), and on the right is the new SO (semiconductor outline). On the left is the present standard TO-92 transistors; its new counterpart is shown at the bottom.

In addition to these circuits, a variety of standard logic circuits will soon be available. The only difference between these devices and their DIP counterparts is their reduced size. When SO IC's are as widely available as SOT's, they will be a powerful design tool.

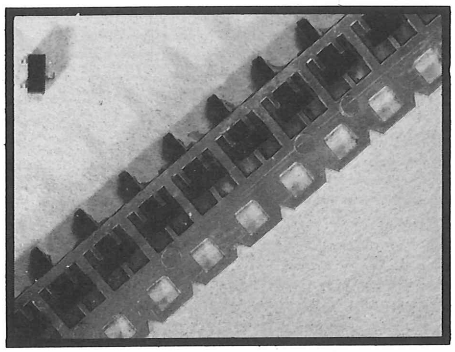


Figure 2. A leadframe, shown with plastic molding applied but before shearing and forming of leads. Finished device shown in the corner.

Prices

The devices currently available include transistor selections from these groups.

—Small-signal (switches and amplifier) devices.

—Low-noise devices.

—HF and UHF devices.

—High-voltage devices.

—FET's.

Diodes, diode pairs, Zeners, switching diodes, Shottky mixers and varactors are also available.

Current prices are competitive with equivalent TO-92 package devices. More exotic devices will be more expensive than their TO-92 counterparts. However, these devices are low cost compared to the cost of assembling chips on hybrids using technologies such as chip-and-wire, flip-chip, LID's, and Micro-T's. However, use of automated placement and standard solder-reflow techniques will make this approach cost effective.

HYBRID CIRCUIT TERMINOLOGY

SOT: Prefix used by European manufacturers to designate a particular microminiature package for transistors.

Land: Synonymous with "pad." Refers to a conductive area on a circuit to which interconnects may be attached.

TO: Prefix used to identify a package configuration defined as standard by the Joint Electron Device Engineering Council.

Solder Reflow: Technique of bonding metals by remelting a preapplied solder interface.

Eutectic: (In metallurgy) an alloy that consists of substances combined in such a ratio that the melting temperature is significantly lower than it would be if the substances were combined in a different ratio.

Flux: Substance used as a catylyst in soldering operations to provide tarnish-free surfaces and to lower the surface tension of the molten solder.

Transfer Molding: Process of introducing plastic molding powers into preheated molds at elevated pressures.

Chip and Wire: Techniques of bonding and interconnecting integrated circuit chips.

Vacon and Kovar: Alloys whose coefficients of expansion are similar to that of Silicon.

Flip Chip: An integrated circuit chip that has solder "bumps" at interconnect points to allow it to be directly attached by inverting it on the substrate and reflowing the solder.

Leadframe: A conductive frame from which the leads and chip pad of an integrated circuit assembly are formed. See Figure 2.

LID: Leadless Inverted Device.

Wirebonding: Technique of interconnecting IC chips to leads on other chips by metallurgically bonding minute gold and aluminum wires.

Micro-T: A miniature ceramic transistor package.

DIP: Dual Inline Package.

Naked Chip: An unpackaged device.

CHIP CARRIERS

In applications where hermeticity and reduced size are important, leadless ceramic packages ("chip carriers") provide the hybrid designer with a versatile approach.

Initial reliability tests indicate that ceramic carriers are environmentally rugged, and give the IC maximum protection under severe operating conditions. Hybrid Circuits Engineering is evaluating a sample of chip carrier parts with the tests shown in figure 3.

Test device performance

High temperature, reverse bias
150°C, for 96 hours at 100% of $-V_{CE}$

Test device performance

Temperature shock
15 cycles of −55°C to +125°C with a 10 minute dwell and 10 second transfer

Test device performance

Humidity cycling
10 cycles, 1 cycleday, from −10°C to +65°C at 98% relative humidity.

Test device performance

Pressure
H_2O at 121° C under 15 psi gauge pressure

Test device performance

Figure 3. Hybrid Circuit Engineering has evaluated the new microminiature SO devices by subjecting them to high temperature, temperature shock, humidity and pressure, and by checking preformance after each test.

One advantage of chip carriers is that the IC's can be burned-in, or tested in commercially available sockets prior to their assembly on the ceramic substrate.

prepare substrate

attach connector pins to substrate

dip in flux and solder

clean and reflux

manually or automatically place microminiature components on prepared substrate

reflow solder

remove flux, clean and inspect

Figure 4. Typical procedure for assembling microminiature components on a substrate.

Fabrication

Chip carriers are multilayer ceramic squares with metallized lead pads on the back surface that extend half-way across the package edge (see figure 6). These leads terminate inside the package around the periphery of a metallized cavity.

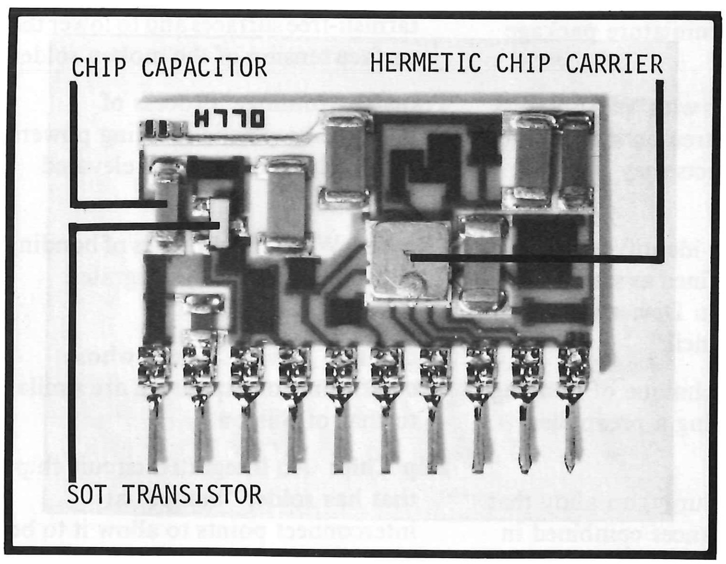


Figure 5. Hybrid Circuit Engineering designed and assembled this hybrid to demonstrate that any combination of SOT's, SO IC's, chip carriers and chip capacitors can, using solder reflow, be assembled in a single operation.

One or more IC chips may be epoxy or eutectic die-bonded to the gold surface. As shown in figure 7, the chip is electrically connected to the terminations (or to another chip in the same cavity) by ordinary wire-bonding.

The leads to the package are typically on 40 or 50-mil centers; they may be attached (using reflow soldering) to solder-coated lands on a ceramic substrate. The top surface of the carrier has a layer of nickel which is plated with 60 micro-inches of gold. The package is completed by using a gold-tin preform to seal an alloy lid to the gold plate.

Advantages

The approach to packaging outlined above has numerous advantages. First, this packaging system provides a hermetic seal around the individual chips. Second, the system allows testing of the hermetically-sealed chip before it is bonded to a hybrid substrate.

Third, it facilitates desoldering and resoldering while still maintaining reliability. Any localized heat source may be use. Also, the configuration of the external leads makes it easier to visually inspect the solder joints.

Fourth, this packaging system reduces the area of the substrate by 3 to 1. Using the 24-to-64 lead chip-carriers reduces the area by two-thirds of the area of DIP counterparts.

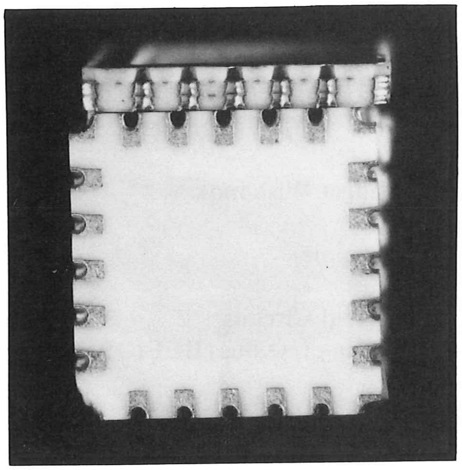


Figure 6. Edge and back views of 300 mil square chip carrier (about 3x magnification).

Fifth, the system triples the high frequency response for typical circuits using chip carriers rather than DIP's. The decreased path length yields lower lead inductance and therefore produces greater frequency response.

The last advantage of this packaging system is that chip carriers mounted on ceramic substrates dissipate heat easily.

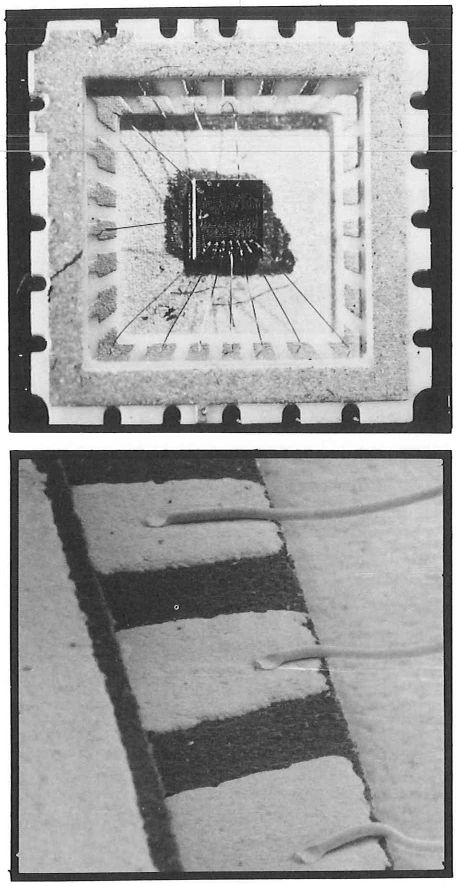


Figure 7. Top: a die mounted in a chip-carrier with wire-bonding. Bottom: Close-up of wirebond on integral terminations (about 50x magnification).

Availability

Furthermore, a large family of chip-carrier designs (in 16 to 64 pinouts) are available from 3M Corporation or Kyocera, Inc. Custom modifications are available from both.

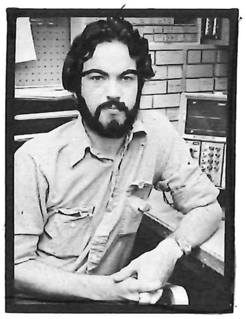
Prices

A recent price quote (for 10K quantities) lists the 16-lead chip carriers at $0.41 and the 64-lead chip carriers at $1.54.

The price of preform-Kovar lids varies with the price of the gold used in them, but prices in the range of $1.25 to $1.50 are typical. The carriers may be ordered without the top metalization and a less expensive ceramic lid may be used instead.

These new packages will provide the hybrid designer with greater versatility, and will facilitate the design of reliable active-device hybrid circuits.

KEITH PARKER ANNOUNCES THE WIDGET WISHBOOK



Keith Parker, Hybrid Circuits Engineering, ext. 6055.

Keith Parker (Hybrid Circuits Engineering) has announced **The Widget Wishbook,** a collection of design ideas stored on the Cyber system.

The wishbook offers designers a chance to make their ideas available to the Tektronix engineering community even though they may not have had the time and resources to fully implement the ideas. The wishbook will thereby serve two purposes. First, it will make concepts available to those who do have the resources, time and specific need for the ideas; and, second, the wishbook will help people with mutual interests make contact.

The wishbook will complement the **Special Design File** (abstracts of finished designs) and the **Designs Wanted** column (requests for specific designs) initiated in the last issue of **Engineering News.**

HOW IT WORKS

If you have an idea you would like to put into the Wishbook, enter the idea in the BARB format, chapter by chapter. (BARB is a Cyber text processing program; to find out how to use it, type in WRITEUP, BARB on any Cyber terminal.) To make your file public, answer the user number request with UN=IFDOKWP and then send Keith a memo at 50-389. The memo should include the file name and your user number. Keith will let you know after he enters it into the wishbook so that you can delete your file if you wish.

FORMAT

The first paragraph of this entry should include a brief description of the design, your name and the date you are entering the design. The first paragraph of each chapter will be entered in the wishbook index (WWINDEX). Figure 1 shows the format for an entry into the wishbook. Figure 2 is a list of entries now in the wishbook.

```
M4,F75,61,72
7L2
TEXAMPLE
P
 THIS IS AN EXAMPLE OF AN ENTRY TO THE "WIDGET WISHBOOK".
 THIS PARAGRAPH WILL APPEAR IN THE WWINDEX, TOO.
 KEITH W. PARKER, HYBRID CIRCUITS ENGINEERING, 18 AUG 77.
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Figure 1. The first paragraph of an entry to the Wishbook should include a brief description of the design, your name and the date you are entering the design.

WIDGET WISHBOOK TABLE OF CONTENTS 77/08/18

Figure 2. The first table of contents for the Widget Wishbook shows an introduction, an example, 10 of Keith's wishbook ideas, and an index.

HYBRID CIRCUITS ENGINEERING I/O BUS

The following is a full description of one of the Wishbook entries, HCEIOB.

This bus provides a structure to which register level microprocessor I/O devices may be interfaced. The bus may then be interfaced to any of a wide range of processors in a manner that will allow all previously designed I/O devices to be immediately useable. In addition, the physical configuration is highly versatile because a flexible 50 conductor flat cable that accepts a wide range of crimp-on connectors carries all signal and voltage lines. Of course, a rigid E.C. board could be used instead. Keith W. Parker, HCE, Aug 77.

The bus consists of 8 bidirectional data lines, 8 address lines, 5 control lines, 8 power lines supplying 3 voltages, and 21 ground lines for a total of 50 lines.

All data transfers use a simple handshake protocol. This gives high-speed operation without making the interfacing of slower speed devices cumbersome. The bus supports eight levels of interrupts.

Possible applications are process and experiment automation, a prototyping tool for microprocessor based instruments, or an applications board that will support microprocessor design aid and O.E.M. operations.

PHYSICAL DEFINITION

The HCEIOB uses a 25/50 Pin, 0.1" cntrs. E.C. connector. This allows the use of 50-conductor "Scotchflex" ribbon cable with crimp-on E.C. connectors inside the card cages and between cages.

PIN	SIDE B	SIDE A
1	+15 V	+15 V
2	+ 5 V	+ 5 V
3	+ 5 V	+ 5 V
4	-15 V	-15 V
5	GROUND	DATA 7
6	GROUND	DATA 6
7	GROUND	DATA 5
8	GROUND	DATA 4
9	GROUND	DATA 3
10	GROUND	DATA 2
11	GROUND	DATA 1
12	GROUND	DATA 0
13	GROUND	ADDRESS 7
14	GROUND	ADDRESS 6
15	GROUND	ADDRESS 5
16	GROUND	ADDRESS 4
17	GROUND	ADDRESS 3
18	GROUND	ADDRESS 2
19	GROUND	ADDRESS 1
20	GROUND	ADDRESS 0
21	GROUND	VIOA
22	GROUND	IORD
23	GROUND	IOST
24	GROUND	RESET
25	GROUND	IOACK
ALL SIGNALS ARE LOW TRUE		

Pin assignments for the HCEIOB.

All signal lines are on the back side of the E.C. board. This causes signal lines to be alternated with ground lines in the "Scotchflex" cable. Power lines are common to both sides of the connector.

The standard card is 4.5" high and 6.5" long with a 25/50 pin, 0.1" E.C. connector centered 0.25" above the centerline of the board on the left hand 4.5" side when looking at the component side of the E.C. board. There are two 0.4" deep cutouts to allow the board to be inserted into the connector. There are two rows of unplated #29 holes to pass #4 screws 0.25" from the top and bottom edges on 0.5" spacing. This pattern starts 0.25" in from the front panel side of the card. The card may stand alone in a card cage or be incorporated into a module for shielding and/or physical protection. Pins 1A and 1B are at the top of the connector and pins 25A and 25B are at the bottom. Side A (back) is on the right looking into the connector and side B (component side) is on the left.

TORSIONAL VIBRATION MEASUREMENT TECHNIQUES

Bill presented this paper at the 1977 Instrument Society of America conference in May in Las Vegas.

Bill Verhoef, Environmental Lab, ext. 7887.

ABSTRACT

Torsional (angular) vibration is present in all rotating mechanisms. This type of vibration is not as easily detected or felt as linear vibration, unless the torsional vibration creates sound or linear vibration. This paper first presents basic concepts of torsional vibration: its causes, effects and some possible cures. Further, it describes various types of transducers used to measure the amount and frequency of torsional vibration.

The paper looks at one method of measurement in particular: using an inexpensive, single-track, optical encoder that is commonly used with numerically controlled machines.

TORSIONAL VIBRATION

Torsional vibration is the periodic change in angular position, velocity or acceleration of a seismic mass.

The amplitude of a pure sinusoidal torsional vibration can be expressed as $\Theta(t) = \Theta \sin \omega t$ radians or degrees. Velocity then is $\dot{\Theta}(t) = \omega\Theta\cos\omega t$ and angular acceleration is $\ddot{\Theta}(t) = -\omega^2\Theta\sin\omega t$, where:

Θ = the peak amplitude of the torsional vibration in radians or degrees and

ω = 2 pi x vibration frequency.

The ω^2 factor can produce very high angular accelerations at higher frequencies, resulting in very high torques when a large mass is involved because $T = \ddot{\Theta} \times I$, where:

I is the mass moment of inertia in lb-in-sec^2,

$\ddot{\Theta}$ is the angular acceleration in rad/sec^2, and

T is the torque in lb-in.

There are surely going to be problems when the torsional vibration forced upon a shaft-mass system is near (or on) one of the system's resonant frequencies. When the system is vibrating at a resonant frequency, the system is said to be operating at a critical speed. A small amount of torsional vibration is then greatly amplified. The amplification is only limited by the amount of damping (friction) that is present in the shaft material, bearings and couplings.

See figure 1. The resonant frequency for a single shaft-mass system (where a small mass connects to a much larger one) is:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{I}} \text{ Hz}$$

where k = shaft torsional stiffness in lb-in/radian.

See figure 2. For two masses connected by a shaft,

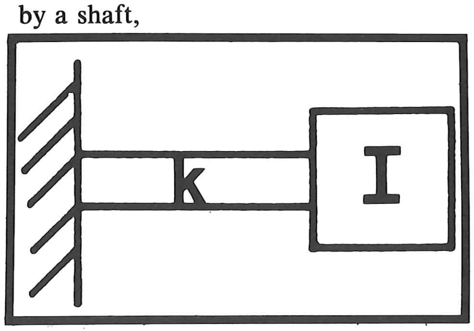

Figure 1. Single shaft-mass system.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K(I_L + I_S)}{I_L I_S}} \text{ Hz}$$

When many more masses and shafts are involved, finding the resonance frequencies becomes much more complex, necessitating the use of graphs and tables or a digital computer.

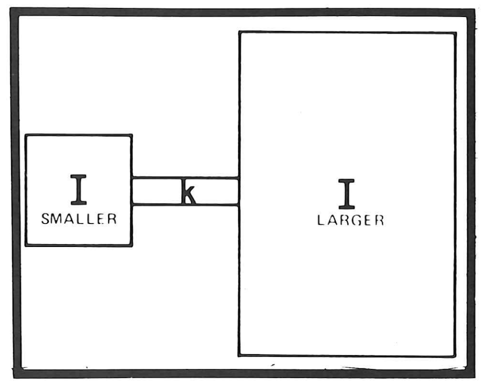

Figure 2. Two-mass system.

CAUSES OF TORSIONAL VIBRATION

Reciprocating engines and pumps

The torque delivered or required by these machines is far from "smooth". The varying torque components in a single-cylinder, 4-cycle engine have frequency components of .5, 1, 1.5, 2, 2.5 (and so forth) times the speed (in rpm) of the engine. A six-cylinder engine with 120° crank spacings has 3, 6, 9, 12, etc., times frequency components.

Electric Motors and Generators

Most electric motors give off torque with a torque component varying at a frequency of two times the line frequency, quite noticeable at high-load conditions such as startup.

The pulsing characteristic of the electric motor can be used to build an inexpensive torsional-vibration exciter. A standard electric motor, found in many appliances, can be made into an electrodynamic shaker by connecting its three wires to an audio power-amplifier with diodes in series with the run and start winding leads. (See figure 3.)

The diodes allow only opposing currents in the run and start windings. The opposing currents prevent the motor from turning over. Instead, it just sits there and vibrates.

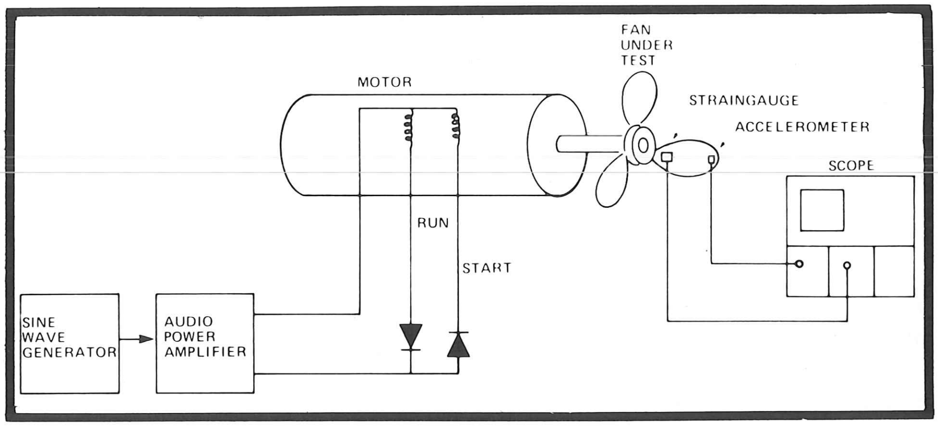

Figure 3. Electrodynamic torsional shaker using a standard motor.

Gears, Pulleys, Couplings, Bearings

Gear and pulley eccentricity, tooth-to-tooth errors, loosely mating gears, and worn gears can cause torsional vibration. Backlash in loose couplings and bearings with high friction spots can be the cause of problems. U joints are well known for creating second harmonic (2 x rpm) torsional vibration. In fact, they do it so reliably that they are used to calibrate torsional vibration transducers. (See figure 4.)

Propellers and Fans

Pulsing loads on propellers and fans, caused by blades passing fixed objects, also produce torsional vibration.

Others

Cam shafts, slipping belts, gear pumps, detent mechanisms, and stepper motors are other sources of vibration. Let's look at an example. Condensed steam interacting with the inside ribs of a rotating, hollow drying drum (in a paper making machine), created enough angular vibration to wear out the drum drive gears.

CURES

Flywheels are used primarily to store kinetic energy, but they also reduce the amplitude of torsional vibration because $\Theta = T/I$. In other words, with a given torque fluction, we can reduce the torsional acceleration by increasing the mass moment of inertia I.

Other remedies are:

—more cylinders in an internal combustion engine (overlapping power stores)

—stay away from resonances by changing shaft stiffnesses

—tight couplings

—free-running bearings.

Another way to reduce these vibrations is by means of dampers. Dampers are made of a seismic mass coupled to the shaft by dry or fluid friction. Another kind of damper uses "tuned-in" pendulum masses to dampen a particular resonant frequency.

EFFECTS

Excessive torsional vibration causes fatigue failures, shaft fractures, and worn couplings, gears and bearings. In reciprocating engines, it also creates excessive linear vibration, and objectionable noise from banging couplings, gears and bearings.

MEASUREMENT TECHNIQUES

There are various ingenious ways to measure torsional vibration. Most mechanical and electrical torsional vibration transducers use a spring-mass system, with a very low torsional resonance frequency (see figure 5). The spring is a flexible torsion bar, a helix spring or sometimes the attraction force of a permanent magnet.

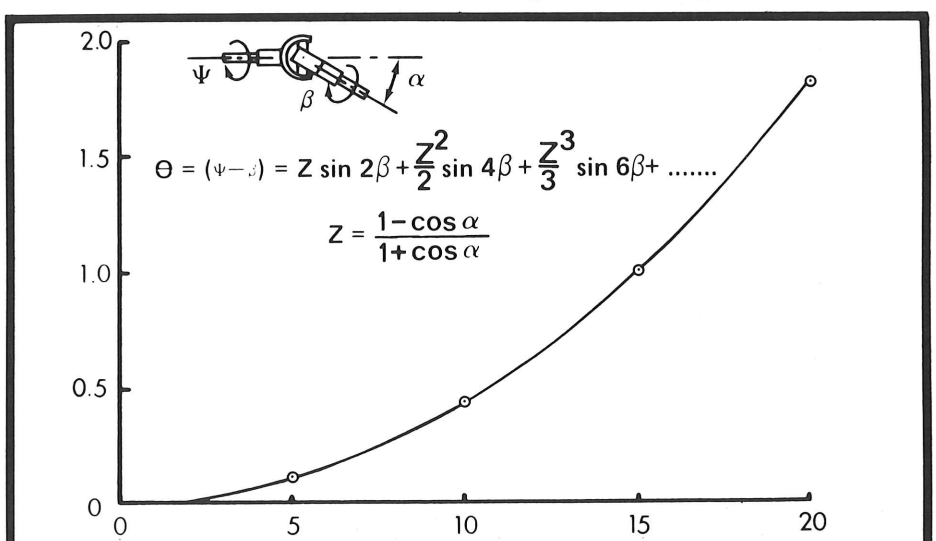

Figure 4. Angular vibration of U joint.

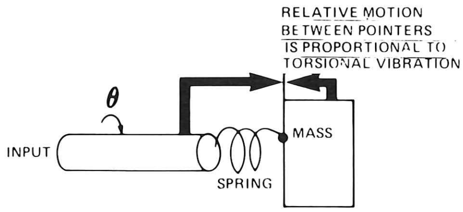

Figure 5. Angular seismic mass system.

When the torsional vibration frequency of the input shaft is higher than the resonance frequency of the transducer spring-mass system, the mass will be isolated from the torsional vibration. The mass will stand still and become the reference point for measuring the amplitude of the torsional vibration. Some of the spring-mass type of transducers use slip-rings to get the electrical signal from the rotating transducer. Others have a stationery sensing circuit, doing away with slip-rings.

For measuring the relative motion between the input shaft and the mass, the same basic principles are employed as commonly used for linear displacement transducers. Typical transduction methods used are: self-generating inductive, linear-variable differential transformer, strain gauge on beam, capacitive, peizoelectric, light sensors, and eddy-current proximity. There are also transducers using neither spring-masses nor slip-rings. Three such methods are described later on.

Torsional Vibration Transducers Using Spring-Mass Systems and Slip-Rings for Transmission of Electrical Signals

Mechanical Torsiograph. Figure 6 shows an example of a mechanical torsiograph from General Motors—a refinement of earlier Geiger and Sommers instruments. The relative displacement between the seismic mass and the input shaft actuates an indicating stylus through a mechanical linkage. The stylus then records the motion on paper attached to a hand-held disk which is momentarily pressed against it, creating a circular chart recording of the torsional vibration for every rotation.

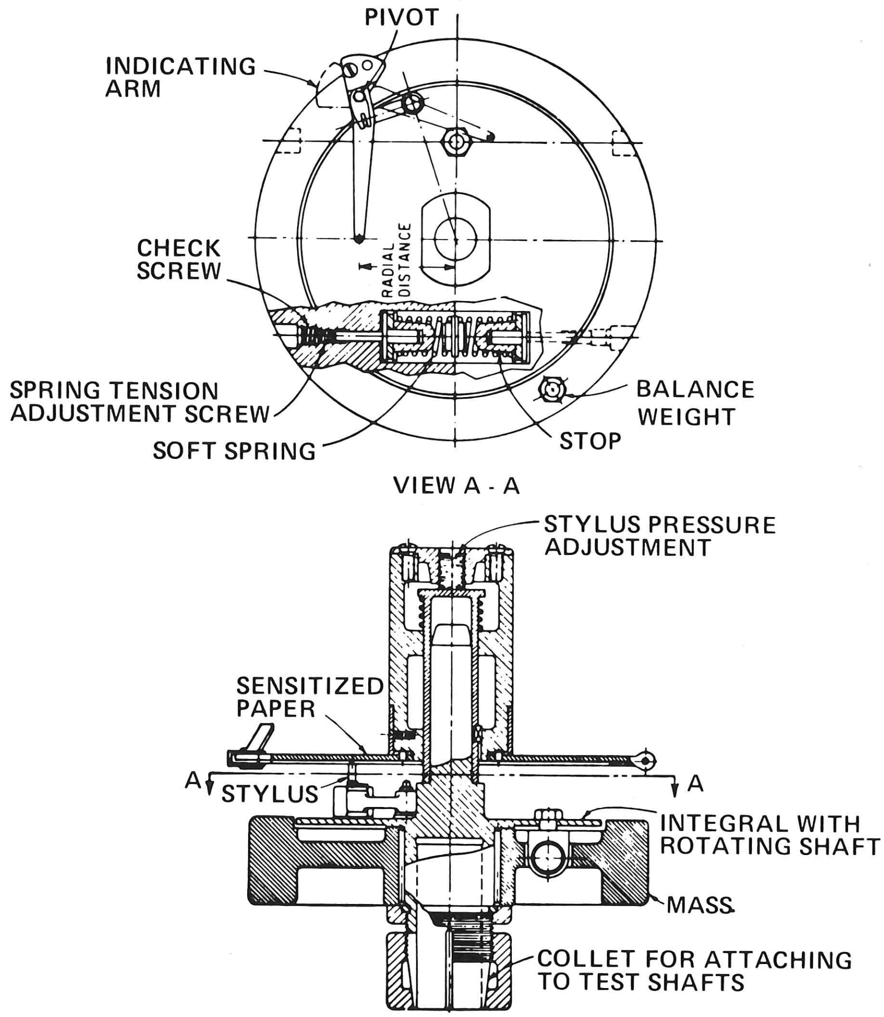

Figure 6. Mechanical torsiograph.

Inductive Self-Generating Torsional Vibration Pickups. Figure 7 shows the operation of an inductive pickup made by Consolidated Electrodynamic Corp. The mass is a magnet mounted on ball bearings placed around an armature. The armature is attached to the input shaft. The strong magnetic field, besides functioning as the spring, also generates a voltage in the armature-coil whenever torsional vibration moves the coil in the field. The output is proportional to the angular velocity with the following specifications.

—sensitivity: 9 mV/degree/sec

—frequency range: 10-10,000 Hz

—maximum amplitude: 2°

Figure 8 shows an inductive self-generating pickup designed by Institute TNO (Toegepast Natuurweten Schappelijk Onderzoek) in the Netherlands. The pickup is held against the outside surface of the shaft to measure torsional vibration in shafts "without ends", such as the shaft between a propeller and an engine in a ship.

The disks A (with O rings) are pressed against the shaft transmitting the rotational motion to magnets H. The armature (and mass) F, along with coils G, form a spring-mass and transducer system similar to the CEC pickup. The signal is transmitted through contacts D to the connector in the handle of this hand-held instrument. Sensitivity is 160 mV/rad/sec. Maximum frequency is approximately 75 Hz. The frequency depends on the properties of the rubber O rings and the contact pressure.

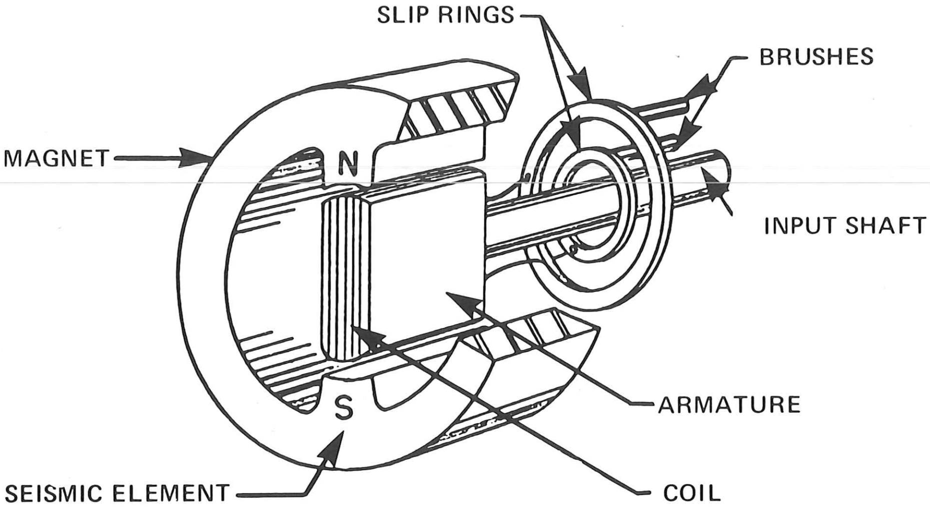

Figure 7. C.E.C. torsional vibration inductive pickup.

Strain Gauge Type Torsional Vibration Transducers

Figures 9 and 10 show a transducer designed by David E. Hamann (Oregon State University thesis). The transducer contains two cantilever leaf springs that form the spring connection between the seismic mass and the input shaft. Relative motion between the input shaft and seismic mass deflects the spring, and causes an output from the four strain gauges that are hooked up into a wheatstone bridge.

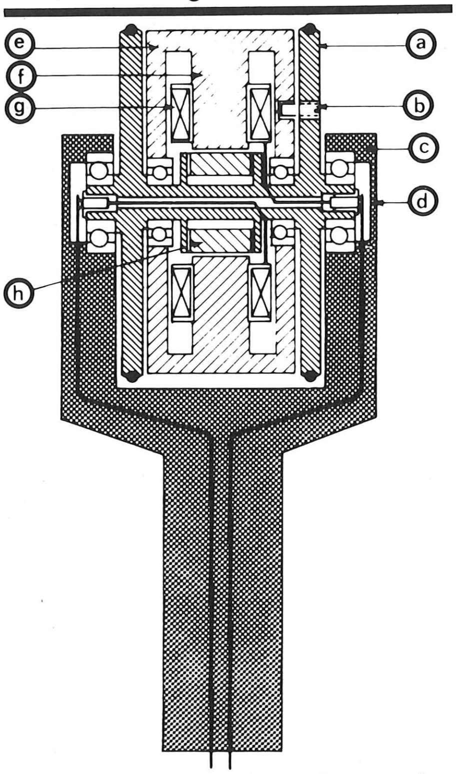

Figure 8. An inductive self-generating pickup.

The output voltage is proportional to the angular displacement of the input shaft, and can be easily calibrated statically by holding the mass and turning the input shaft a known amount. Maximum rotational displacement is approximately 10° peak-to-peak. The output sensitivity is approximately 5 mV/degree with a 10-volt supply. Resonant frequency is approximately 7 Hz. The usable frequency range is from 15 Hz to greater than 110 Hz (the highest frequency tested).

Unbonded Strain Gauges and Liquid Seismic Mass. Figure 11 shows an angular accelerometer made by Statham Laboratories. It contains a paddle A suspended by strain-sensitive wires (the unbonded strain gauge).

The housing is filled with a fluid. The fluid performs the function of the seismic mass. The unbonded strain gauges serve as spring and sensor. This transducer is used below its resonant frequency, whereas the transducers mentioned before operate above the seismic resonant frequencies.

The viscosity of the fluid and the gap between the baffles B and the paddles A provide the correct amount of damping, allowing the transducer to be used near its resonance frequency.

Vibrating Wire Sensor. Figure 12 shows a rate-of-turn sensor made by the Aerospace Division of Honeywell. The sensor's operating principle can also be used for torsional vibration measurements.

As shown, the wire is forced to vibrate by the drive magnet. Rotation of the sensor causes the wire inside the signal magnet to deviate from a staight line vibration due to coriolis forces, resulting in the wire moving through the magnetic flux lines. The amplitude-modulated output signal is proportional to the angular velocity of the input shaft (rate of turn).

Electrical Transducers with Spring-Mass System, Without Slip-Rings.

Two Gears and Magnetic Pickups. Figure 13 shows tow magnetic pickups whose output is amplified, shaped and used to set and reset a flip-flop. (See figure 16). The time between the set and reset pulses is determined by the angular deflection of the torsion bar. The angular deflection is proportional to the torsional vibration amplitude.

The flip-flop's output voltage is on for a longer time during a larger twist in the torsion bar. A filter averages the output signal, removes the shaft speed component, and presents the torsional vibration signal to the scope. The gears, of course, must be in perfect condition, without any tooth-to-tooth errors or eccentricities.

Two Photoelectric Encoder Disks. Figure 14 shows two encoder disks connected to a spring-mass system. A stationary lamp and photocell arrangement detect the relative angular motion of the disks caused by the torsional vibration. Light transmission from the lamp to the photocell changes linearly with the relative position of the slits in the disks.

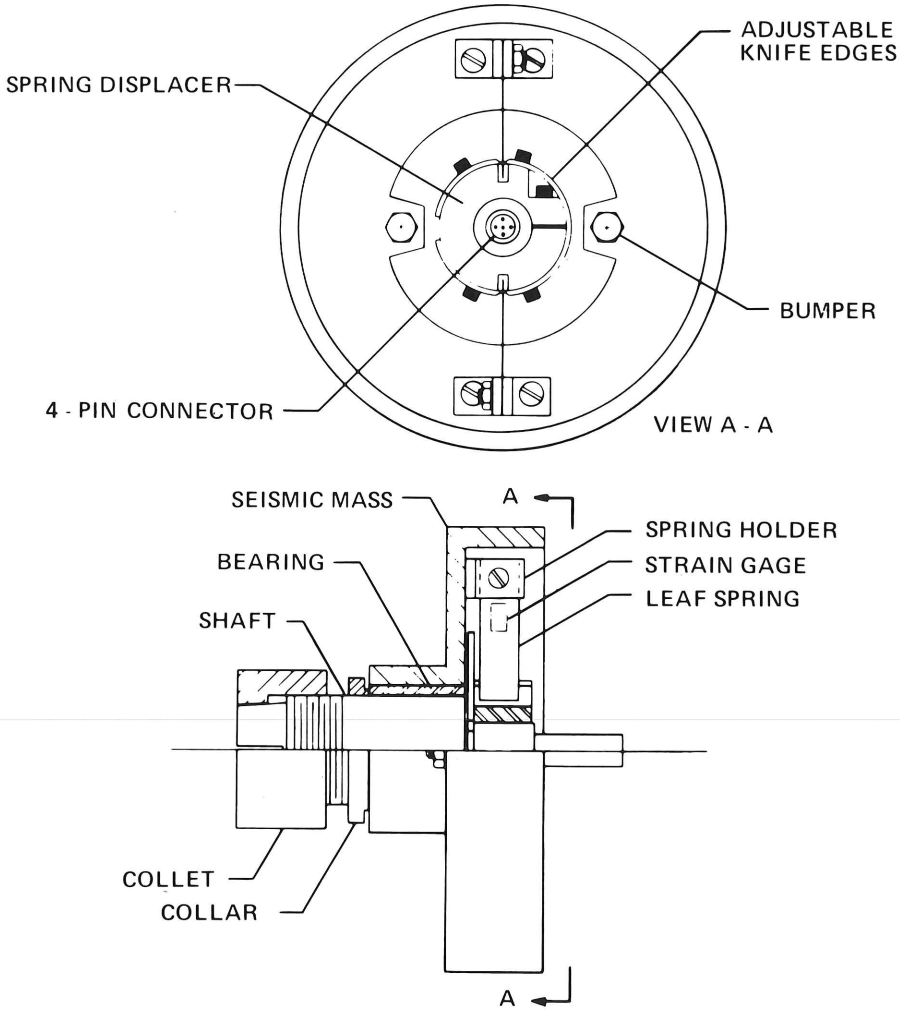

Figure 9. Cantilever, straingage transducer.

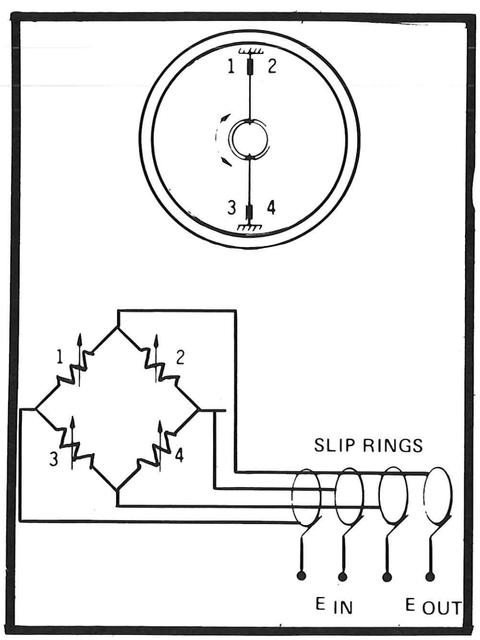

Figure 10. Straingage location and circuit of transducer in figure 9.

Electrical Transducers Not Using a Spring-Mass System or Slip-Rings.

Eddy-Current Generator. Figure 15 shows how the transducer (made by Hoodwin Instruments) operates using a metal disk as its main sensing element. The disk, connected to the input shaft, rotates near a permanent magnet which generates eddy currents in the disk.

A pickup coil on the other side of the disk senses the changes in these currents. Torsional vibration produces current changes. The output voltage is proportional to the angular acceleration of the input shaft. The sensitivity ranges from .1 to 10 mV/rad/sec^2 depending on the disk material used and the pickup coil. Resonance frequency ranges from 800 to 3,000 Hz.

Maximum rpm of the input shaft is limited by the heat generated in the disk. The speed ranges from 500 to 5800 rpm, depending on the disk materials and the method of cooling used.

Magnetic Tape Torsional Vibration Pickup. Figure 16 shows a system that can be used to measure flutter in a tape transport as well as torsional vibration in a shaft.

A piece of magnetic tape is attached to the circumference of a drum or shaft. Three tape heads are held against the moving tape, an erase head, a write head and a read head. The erase head continuously erases (cleans) the tape.

The write head records a sinusoidal signal on the tape.

The read head detects this signal. The phase angle between the write and read signals is a function of the speed of the tape. The circuit shown in figure 16 converts this phase change to a voltage that is proportional to torsional vibration.

If the bandwidth of the tape heads is high enough, pulse-type signals can be used instead of sinusoidal signals, eliminating the need for pulse generating circuitry.

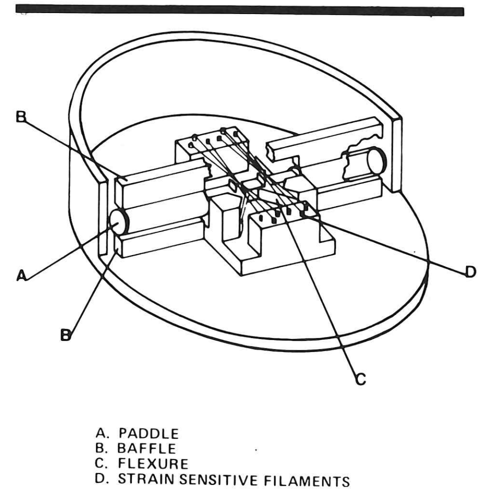

Figure 11. Liquid rotor angular accelerometer.

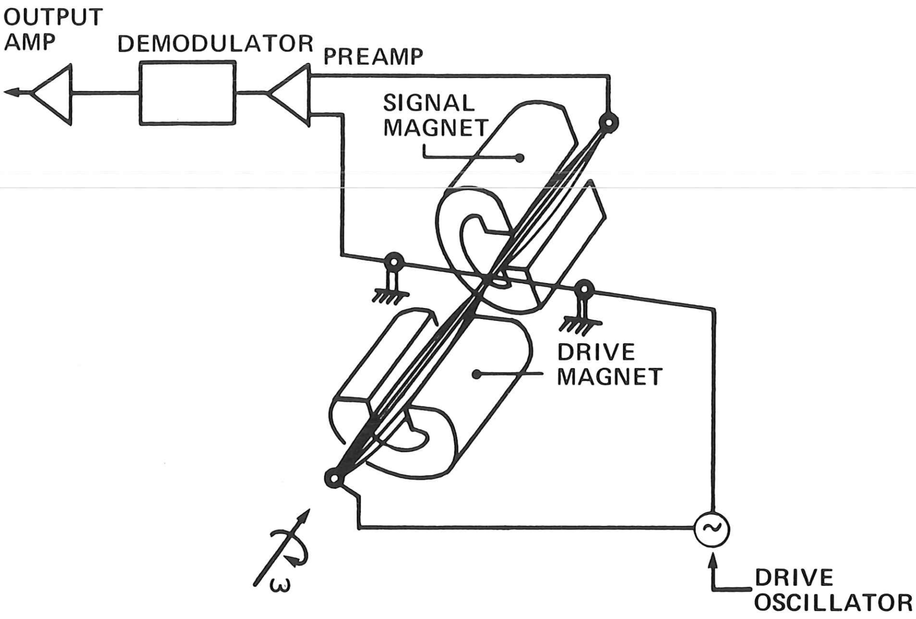

Figure 12. A rate-of-turn sensor.

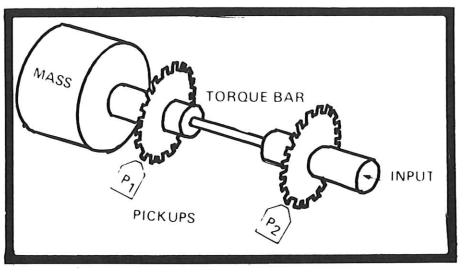

Figure 13. Transducer using magnetic pickups and gears.

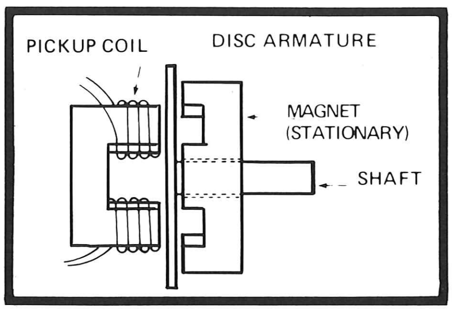

Figure 15. Eddy current generator.

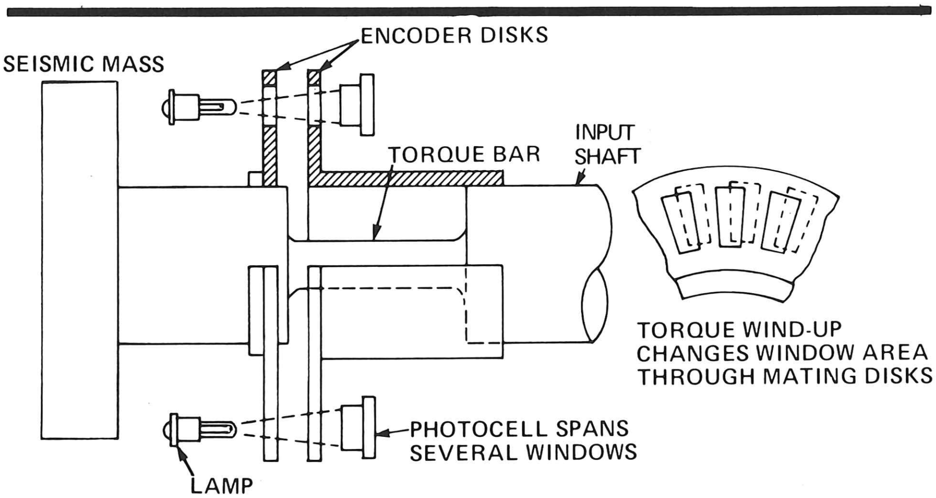

Figure 14. Photoelectric transducer with two encoder disks.

Single Disk, Single Track, Standard Photoelectric Encoder. Figure 17 shows how a standard encoder, commonly used as a shaft-position sensor for numerically controlled machines, can also sense shaft speed and torsional vibration, without adding any springs, seismic masses or slip-rings. The figure shows the encoder hooked up to a U joint vibration calibrator.

The pulses from the encoder trigger a pulse generator to produce the pulses with a constant time duration. The following low pass filter and integrator circuits convert the pulses into an average voltage that is proportional to the speed of the shaft (the dc component) and the torsional vibration angle (the ac component). The shaft speed or vibration is measured by switching the scope input to either the dc or ac position.

Using the circuit in figure 18, an encoder with 500 pulses/revolution and 5 V, 20 microsecond pulses from the pulse generator produced a sensitivity of 1 mV/degree of torsional vibration, and .8 mV/rpm dc signal for shaft-speed measurement. Filter characteristics determine the frequency limits of this system. With the filter shown, the output is proportional to angular vibration between 3 and 100 Hz. Replacing the 7.5 kilohm resistors with 1 kilohm resistors would bring the max frequency up to 750 Hz, but also increases the noise-to-signal ratio.

The maximum amplitude is limited only by the acceleration capabilities of the encoder (pretty high!). The pulse frequency capability of the encoder determines the maximum rpm. With 500 pulses/revolution, the maximum was about 10,000 rpm for the encoder we used. Calculated sensitivities were verified with a U joint used as torsional vibrator. Figures 19 and 20 show the angular vibration of a single-cylinder lawnmower engine, driven by an electric motor, measured with the encoder. A loose and occasionally slipping drive belt caused severe torsional vibration.

Figure 21 shows a scope display of the speed and angular acceleration of an electric motor-flywheel system when turned on and off using the same encoder as sensor. The scope displays speed when the scope is dc coupled, and shows low frequency angular acceleration (less than 3 Hz) when ac coupled.

ACKNOWLEDGMENTS

Figure 11 (the liquid rotor angular accelerometer) comes from a **Statham Instrument Note** originally published by the Test Instruments Division of Honeywell (Denver, Colorado).

Figure 12 comes from the May 25, 1970, issue of **Design News** on page 30. The GG1102 rate-of-turn sensor was a product of the Aerospace Defense Group of Honeywell (Minneapolis, Minnesota).

Figure 14 comes from the October 23, 1967, issue of **Electrical/Electronic Power and Control** on page 3. The shaft-encoder technology Model TQ transducer is a product of Vibrac Corporation (Chelmsford, Massachusetts).

Figures 19, 20, 21 come from the April 18, 1977, issue of **Machine Design** on page 142.

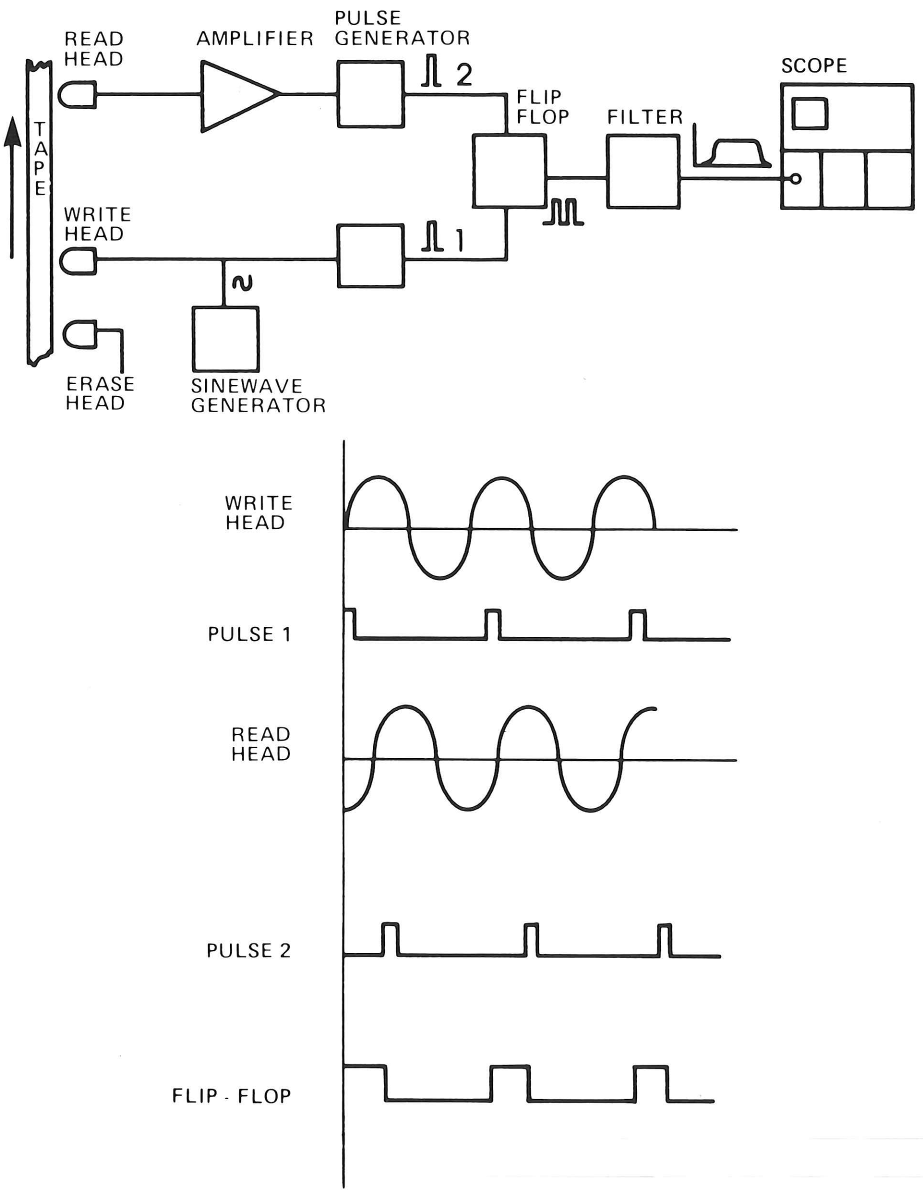

Figure 16. Magnetic tape and tape head transducer.

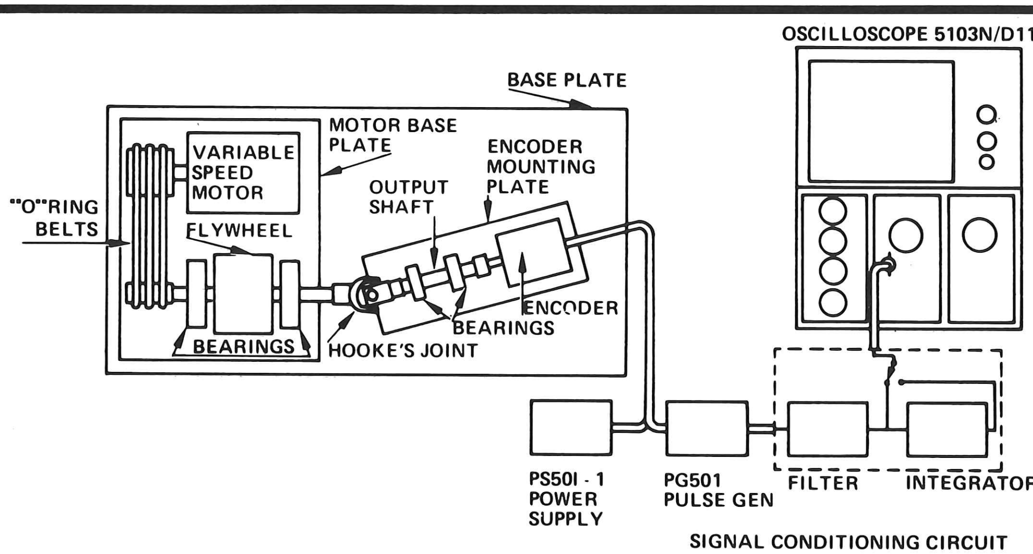

Figure 17. Standard photoencoder used as torsional vibration.

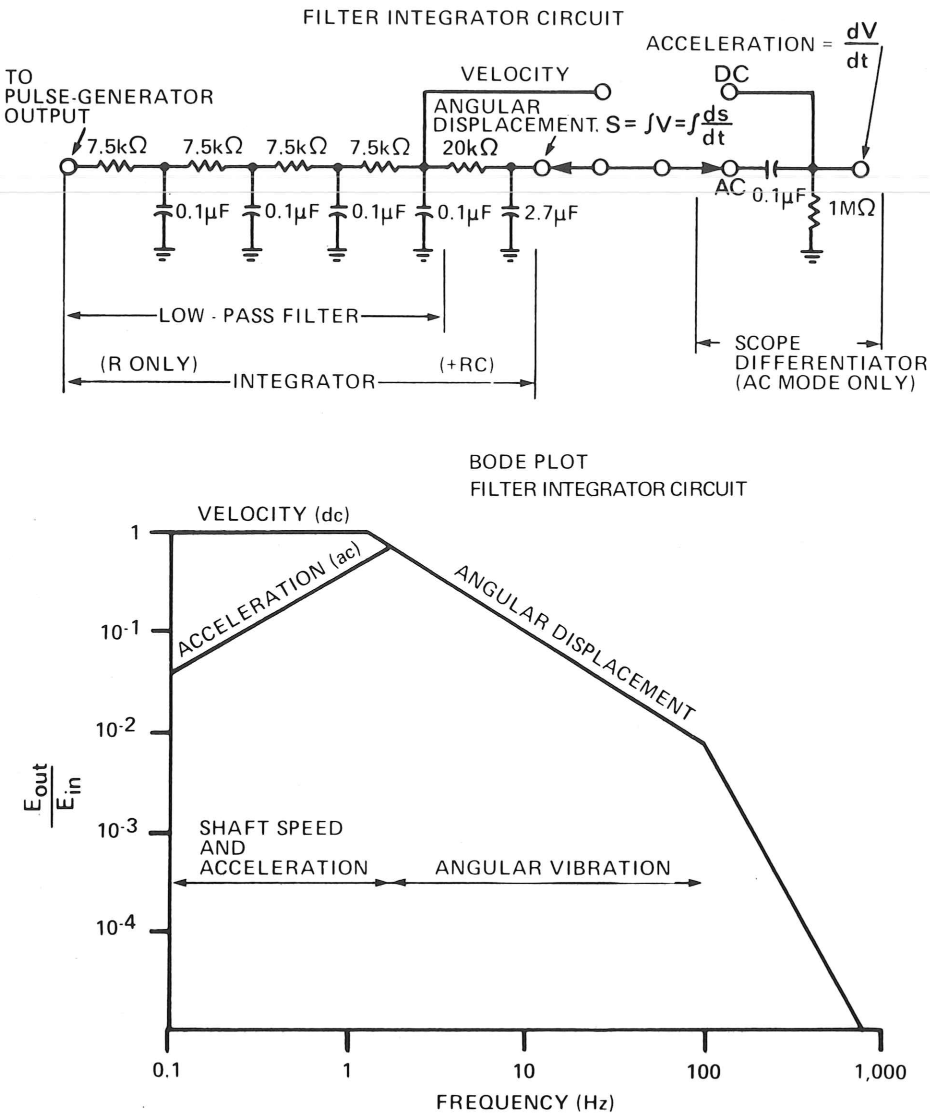

Figure 18. Filter/integrator circuit for encoder and overall performance plot.

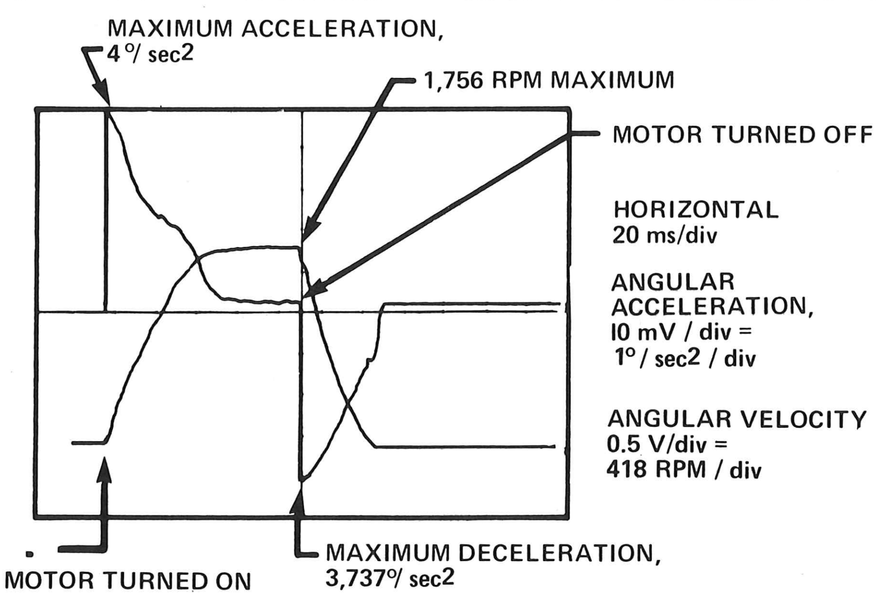

Figure 19. Torsional vibration of single-cylinder engine.

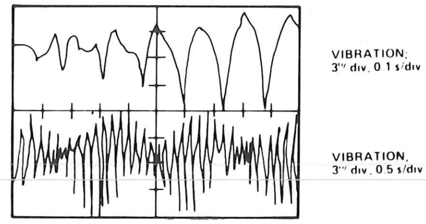

Figure 20. Torsional vibration of single-cylinder engine.

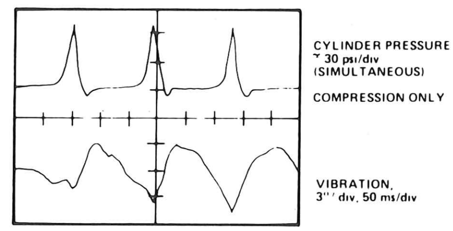

Figure 21. Motor-flywheel start-up and turn off speed and acceleration.

PATENTS RECEIVED BY TEKTRONIX

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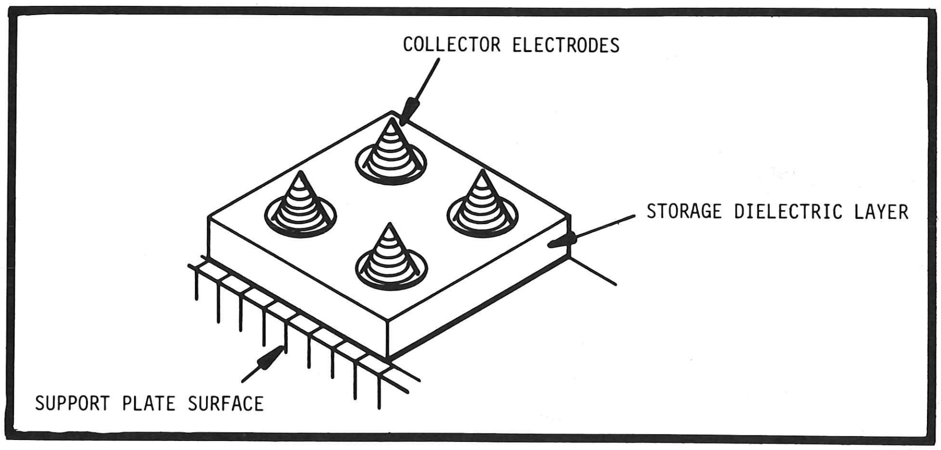
All back up material for the patents is on file in the Patents and Licensing Office (D.S. 50-419). For more information about patents in general, call ext. 5266.

A CATHODE RAY STORAGE TUBE

Edward R. Steele (Display Device Engineering), ext. 7510.

This cathode ray storage tube has a storage target that contains many segments of the collector electrode extending through the dielectric layer of the storage target.



The segments are made up of glass beads secured together and also secured to the surface of an insulating support plate. A conductive collector-electrode coating is applied to the support plate surface in such a thickness that the segments extend above the dielectric.

The exposed segments collect secondary electrons emitted by the dielectric.

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