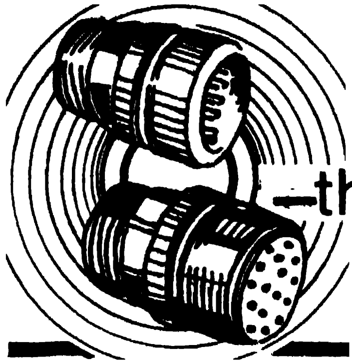

Circular Connectors —their Proper Usage and Reliability

George Olikara

The present-day trend of modular construction of electronic and electrical equipments has caused a rise in the use of a wide variety of connectors. The use of the circular connector, under which category fall a very wide range of connectors, from the simple audio connector used in domestic stereos to highly sophisticated umbilical connectors used in missiles and rockets, has increased the most.

The discussion here is restricted to two types of circular connectors which are most widely used in professional electronics in India. These are the MIL-C-5015G (JSS-50812) and MIL-C-26482 (JSS-50813) connectors.

Construction

A circular connector essentially has three components: (i) the contacts, (ii) the insulator, and (iii) the shell, as shown in Fig. 1.

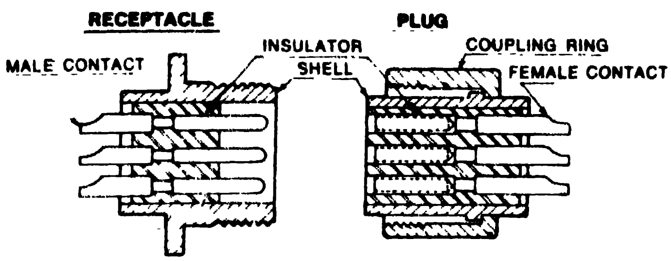

Fig 1

The contacts are the current conducting paths and are usually made of copper alloy. The insulator insulates the current conducting contacts from each other. It is made of various plastics or rubber. The main function of the shell is to protect the inside components from damage, and in certain cases act as a shield against electromagnetic radiation and radio frequency interference. The shells are made of either steel or aluminium alloy.

A connector has two mating halves. The half which is fixed on a panel is called a receptacle and the half which is fixed on the cable is called the plug. The exact design of these connectors (which is different for different manufacturers) is such that they meet the stringent specification of MIL-C-5015 (JSS 50812) or MIL-C-26482 (JSS 50813).

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These specifications cover such tests as climatic cycle, temperature cycling, vibration, impact, mating cycle, electrical parameters, fluid immersion etc.

As per MIL-C-5015 specification (JSS 50812) the connectors are specified by their shell size which is the outside diameter of the receptacle in multiples of 1.587 mm (1/16th of an inch). The commonly used shell sizes are: 8(12.70 mm dia.), 10(15.87 mm dia.), 12(19.05 mm dia.), 14(22.22 mm dia.), 16(25.40 mm dia.), 18(28.57 mm dia.), 20(31.75 mm dia.), 22(34.92 mm dia.), 24(38.10 mm dia.), 28(44.45 mm dia.), 32(50.80 mm dia.), and 36(57.15 mm dia.).

Under each shell size one can get different numbers of contacts arranged differently to get various working voltages and number of connections. Hence the user has a very wide choice of contact configurations to suit a particular circuitry. For example, Amphetronix Limited manufactures these connectors in technical collaboration with Bunker Ramo Corporation, USA in over 200 different configurations.

Proper usage

The basic requirement of the circular connector design is transmission of maximum electric power for the least possible connector weight while meeting all environmental requirements of the specification.

When the current flows through the contacts of the connector, there is generation of heat due to the I^2R losses. The heat generated raises the temperature of the connector. Both the specifications under reference allow the respective connectors to be operated up to a maximum temperature of 125°C (257°F) resulting from any combination of electrical load and ambient condition. Hence the amperage chosen per contact is such that the temperature rise of the connector is within the limit specified.

Conversely, for a given amperage the designer chooses the smallest diameter possible for the contact to keep down the weight of the connector. Hence one finds that a 16-gauge contact [0.0625-inch dia. (1.59mm dia.)] carries 22 amps, a 12-gauge contact [0.094-inch dia. (2.39mm dia.)] carries 41 amps etc, at the normal temperatures encountered.

One should therefore be careful while choosing a connector for an environment whose temperature is high—say about 75°C to 125°C. The specified amperage per contact

Table 1: Environmental Breakdown

Area	Shock	Vibration	Temperature	Contamination Sources
AFT body fairing (ABF)	3 5G Max	5 to 1000Hz 4 6 mm D A Max	-65°F to 175°F	Moisture, dust hydraulic oils
Air conditioning bay (ACB)	3 5G Max	5 to 1000Hz 4 6 mm D A Max	-65°F to 200°F	Moisture, dust, high velocity gases
Antenna cavity (AC)	3 5G Max	5 to 1000Hz 4 6 mm D A Max	65°F to 175°F	Moisture
Engines (E)	5 0G Max	5 to 1000Hz 3 8 mm D A Max	-65°F to 350°F	Moisture hydraulic oils jet fuel engine oil, hot high velocity gases
Mixing bay	4 5G Max	5 to 1000Hz 4 6 mm D A Max	65°F to 200°F	Moisture dust, high velocity gases
Nose (N)	3 5G Max	5 to 1000Hz 2 5 mm D A Max	-65°F to 175°F	Moisture
Nose wheel well (NWW)	3 5G Max	5 to 1000Hz 4 6 mm D A Max	65°F to 200°F	Moisture dirt hydraulic oil
Pressurised (P)	3 5G Max	5 to 1000Hz 4 6 mm D A Max	65°F to 175°F	Moisture dust
Tail (vertical horizontal tail surfaces) (T)	4 5G Max	5 to 1000Hz 10 2 mm D A Max	65°F to 200°F	Moisture
Wheel well (WHW)	4 0G Max	5 to 1000Hz 2 5 mm D A Max	-65°F to 200°F	Moisture, dirt, hydraulic & jet fuels
Wing (W)	5 5G Max	5 to 1000 Hz 10 2 mm D A Max	--65°F to 200°F	Moisture, dirt, hydraulic & jet fuels

should be derated such that the sum total of the environment temperature and the rise in temperature due to electrical loading is less than the specified temperature of 125°C. It is also important to keep in mind the extent to which a rise in temperature of the connector will be allowed in the place where it is fitted. For example, if a connector is to be disconnected with bare hands by an operator while the supply is on, the temperature of the connector must not rise above 50°C. In both the cases mentioned above one should either go in for a connector with larger diameter contacts or derate the contact amperage.

A third point which must be taken care of is the frequency of the power supply. Both the types of connectors under reference are designed for a DC supply or an AC supply of 50 to 60 Hz. If one uses these connectors for a power supply of 400 Hz to 1000 Hz frequency (which is nowadays used in certain applications), it would cause electric shocks due to arcing and would hurt the operator while he is unmating the connector with the supply 'on'.

The fourth point which should be given serious thought is the service life of the connector. As the temperature of operation increases, the service life of the connector decreases. The military specification requires that the connector should have minimum service life of 60 hours when operating at 125°C and 1000 hours when operating at 85°C. Even though actual connectors have much more service life than specified, one should give a thought to this aspect. The higher temperature increases the oxidation rate, specially of the insert material, causing deterioration of the electrical properties of the material.

Though the materials used in the connector are chosen carefully to stand hostile environments such as certain types of oils, chemicals, etc, one should be careful regarding the exact nature of the environment existing around the place where the connector has been fitted. For example, though the connectors are tested for immersion in fluids (as specified in JSS 50812 and JSS 50813) such as petroleum-based hydraulic fluids used in aircrafts, missiles, lubricating oil used in aircraft turbine engines etc, certain other types of oil cause a swelling of the rubber parts used in the connector. Similarly, highly alkaline or highly acidic atmosphere causes corrosion of the metallic shells. Even though the olive drab chromate coating provides a comparatively hard surface, care should be taken to avoid causing deep scratches, nicks etc during handling and installation. If these scratches expose the base metal, atmospheres saturated with salt mist would cause corrosion.

While selecting connectors, the skill of the assembly operators should always be considered. In the case of connectors with solder terminals, the insulation resistance of the insulating insert is very much reduced if the flux flows onto the insert surface. Similarly, if the excessive solder flows onto the outside of the contact, the effective gap between the contacts is reduced (especially if the solder forms into small globules with pointed sides), and this affects the limiting operating voltages. Crimp contacts are the solution to the above problems.

Table 2: MIL-C-5015 (JSS-50812)

Failure Mode	A			B				C			D				E
	AA	AB	AL	BC	BD	BE	BL	CF	CG	CL	DH	DI	DJ	DK	EL
ABF															
ACB															
ANT															
E		0/1		20	1					11	3	4		0/2	14
MB															
Nose		0/1													
NWW		0/15				1		2					0/1	0/2	1
P															
Tail				1		1				3					12
U															
WHW		0/6		4	1			5		9	10		0/2	0/2	9
Wing				4		1		3		3	1				
Total		0/[illegible]		29	2	3		10		26	14	4	0/3	0/6	36
Failure Mode Total Uncensored	23			34				36			27				36
Failure Mode Total Censored	0			34				36			18				36

Table 3: MIL-C-26482 (JSS-50813)

Failure Mode	A			B				C			D				E
	AA	AB	AL	BC	BD	BE	BL	CF	CG	CL	DH	DI	DJ	DK	EL
ABF															
ACB															
ANT															
E															
M B															
Nose															
NWW															
P		0/2		5							1				
Tail															
U															
WHW															
Wing															
Total		2		5							1				
Failure Mode Total Uncensored	2			5				0			1				0
Failure Mode Total Censored	0			5				0			1				0

CENSORED / UNCENSORED

Reliability

Every buyer is concerned about the reliability of the product he is buying. The concern is very deep if the item is to be used in an installation where failure can cause loss of human lives. Thus, while choosing connectors for use in aircrafts, ships, tanks, power generation units, medical equipments etc, reliability is a very important criterion.

The modern jet aircraft is the one installation where connectors are subjected to the most hostile environments. Hence a reliability study of the connectors under reference, if based on their use in jet aircraft, would cover most of the possible failure modes. The following discussion is based on such a study conducted by Bunker Ramo Corporation, USA.

The data has been compiled from the operations of several major airlines which use the Boeing 727 aircraft. The compilation covers the years 1964 and 1965, and the data encompasses some 525,000 in-flight hours accumulated by 209 aircrafts. This number of in-flight hours results in a total operating time of 88,809,660 hours for the two types of connectors under reference.

The environmental conditions experienced by the connectors are different for different parts of an aircraft. The conditions are almost completely benign in the area of the passenger cabin and are extremely severe in terms of pressure, temperature and contamination sources in some of the uninhabited portions of the aircraft. Table 1 gives an idea of these environmental differences.

In the source data, the primary failure was sought in each instance and it was found that the following failure modes could be identified and categorised.

Category A

Termination failures

A A —Defective termination (i.e. a failure occuring at the contact-wire joint by virtue of bad crimp, or a cold solder joint).

A B —Failure of the wire adjacent to the connector but away from (to the wire side of) the point of wire contact joint.

A L —Specific point or circumstance of failure undetermined but within the generic failure mode.

Category B

Coupling failures

B C —Connector loosened

B D —Connector completely uncoupled

B E —Improperly mated connector (i.e. contacts bent, contacts cocked, contacts pushed back, connector misaligned).

B L —Specific point or circumstance of failure undetermined but within the generic failure mode.

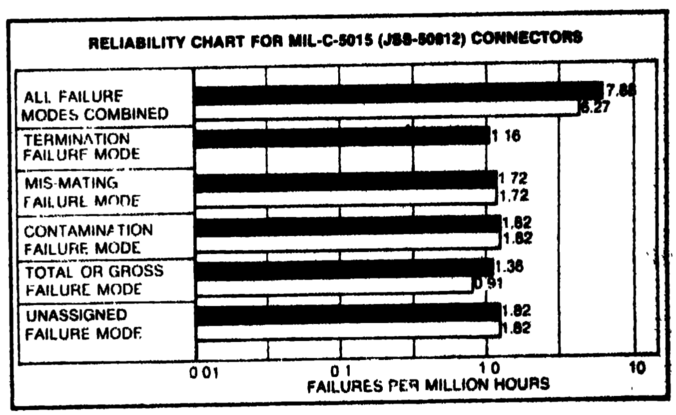

Fig 2

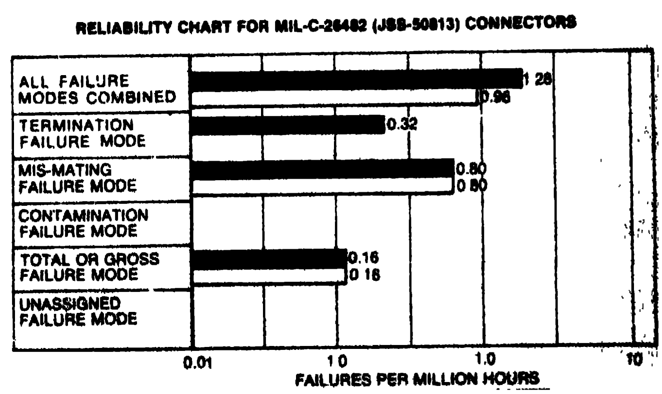

Fig. 3

Category C

Contamination failures

C F —Shorts or excessive leakage between contacts.

C G —Open circuits or high resistance due to dirty contacts.

C L —Specific point or circumstance of failure undetermined but within the generic failure mode.

Category D

Total or gross failures

D H —Connector damaged or broken

D I —Contacts damaged or broken

D J —Connector improperly assembled

D K —Connector improperly installed or wrong connector installed.

Category E

All other failures

E L —All failures which cannot be otherwise placed.

Earlier the total operating time for the two types of connectors under reference has been given as 88,809,660 hours. Even though the figure represents correct total connector operating time, the failure rates must be based on adjusted operating hours. This is because some airlines reported all connector failures while a few reported only those failures causing delays in departures. By comparing the failure rates based on data from airlines reporting all connector failures with those based on data received from airlines reporting only connector failures which cause delay, an adjustment factor of 3.41 to 1 is arrived at. Hence the adjusted hours are arrived at by dividing the actual hours by 3.41.

The failure rate is calculated as follows:

$$FR = \frac{\text{Number of connector failures}}{\text{Number of connector operating hours}}$$

In accordance with accepted reliability techniques, those failures which are not attributable to the device under study are *censored* and not used in computing failure rates. For example, a wire which breaks outside a connector would be censored and not counted as termination failure. Both the adjusted uncensored connector operating hours and the adjusted censored connector operating hours are used for calculating the failure rate and we get the adjusted uncensored failure rate and the adjusted censored failure rate.

Tables 2 and 3 give both total uncensored failures and total censored failures for the MIL-C-5015 and MIL-C-26482 connectors respectively

The total unadjusted and adjusted connector operating hours for both types of connectors are:

MIL-C-5015

Total unadjusted operating hours = 67,422,702 hours

Therefore total adjusted operating hours = 19,772,054 hours

MIL-C-26482

Total unadjusted operating hours = 21,386,958 hours

Therefore total adjusted operating hours = 6,271,835 hours

The failure rate of each type of connector can now be calculated under each mode of failure. For example, the failure rate for MIL-C-5015 under contamination failure mode can be calculated as follows:

$$\text{Adjusted uncensored failure rate} = \frac{36}{19772056} = 1.82 \times 10^{6}$$

The failure rates are calculated for each type of failure and all failure modes are combined and shown by means of bar charts as in Figs 2 and 3.

The MIL-C-5015 is the first generation of circular connectors designed for use in sophisticated military equipments. The original version of this connector type was released on July 27, 1949. The MIL-C-26482 is a second generation connector whose design is much better than that of the MIL-C-5015 connector, especially in its capability to seal the entry of contamination. This can be clearly made out from the reliability charts in Figs 2 and 3. It can be seen from the figures that in other aspects too, the MIL-C-26482 is superior to the MIL-C-5015 type connector and has a higher reliability rating.

The reliability values of each mode of failure are of use both to equipment designers and to other users of connectors, particularly because they can be improved if special care is taken of each failure mode. □