INSTRUMENTATION

INSTRUMENTATION ACCESSORIES

TRAINING MANUAL
Course EXP-MN-SI060
Revision 0

INSTRUMENTATION

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CONTENTS

1. OBJECTIVES

This course aims to teach a future instrument technician about the accessories necessary for the instrumentation equipment present on an industrial site in the oil industry.

At the end of the course, in the instrumentation and standards field, the participant must:

- Know the principal instrumentation accessories

2. ACCESSORIES FOR FITTING TRANSMITTERS

2.1. ISOLATING VALVES

2.1.1. Manifold

The manifold is quite simply an assembly of isolating valves on a same block. Its main job is to isolate a pressure transmitter so that its zero can be calibrated.

2.1.1.1. 2-way manifolds

The 2-way manifold is used for "*conventional*" pressure transmitters. It has a transmitter HP isolating valve and a drain valve.

This type of manifold is very rarely used.

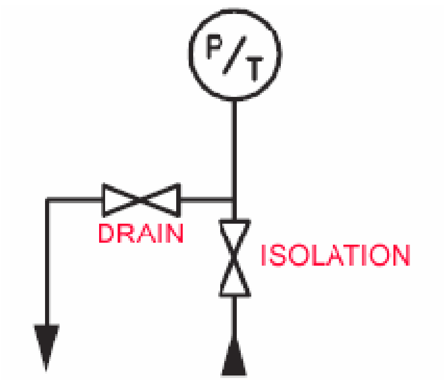


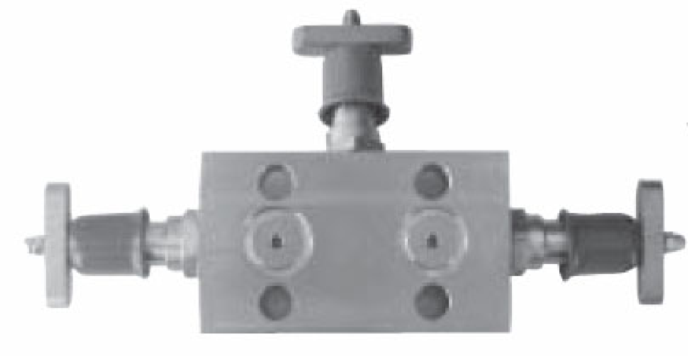
Figure 1: 2-way manifold

2.1.1.2. 3- and 5-way manifolds

The 3- and 5-way manifolds are much used in the instrumentation field, they connect directly to the differential pressure transmitters.

The 3-way manifold combines the isolating and bypass functions.

Using two valves (right and left), we isolate the HP and the LP sides of the transmitter, and we balance the two chambers (HP and LP) using the bypass valve (middle): this facilitates the transmitter zero check when the two measurement chambers are well balanced.



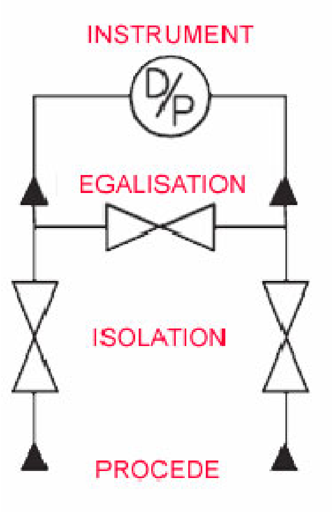
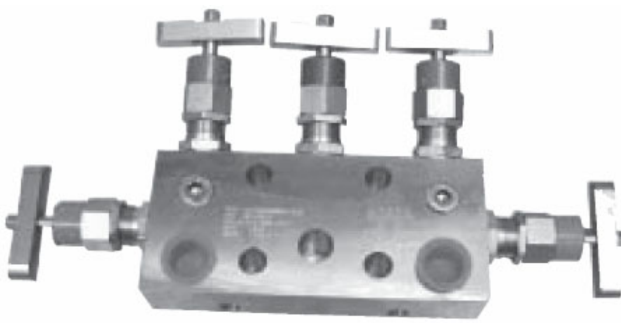


Figure 2: 3-way manifold

The 5-way manifold 5 is identical to the 3-way manifold except that we have added two drain valves. These allow each of the transmitter's measurement chambers to be drained.



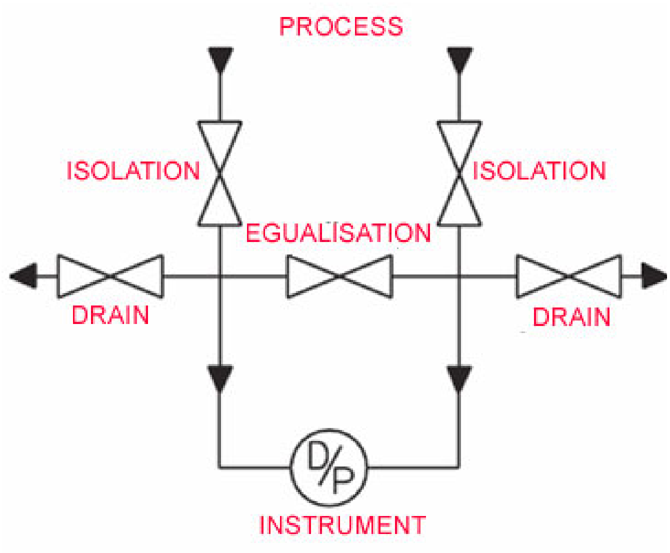


Figure 3: 5-way manifold

2.1.1.3. The manifold and its associated transmitter

In this example, the manifold is mounted directly on the transmitter by means of screws supplied with the manifold.

Figure 4: 3-way manifold associated with a transmitter

2.2. MOUNTING BRACKET FOR REMOTE TRANSMITTER

It is important to talk about the mounting brackets which are available.

When ordering a remote transmitter, do not forget that the mounting bracket is an ***option***.

There are two types of mounting brackets:

- ***Wall mounting bracket,***
- ***Mounting bracket for 2-inch tube.***

2.2.1. Wall mounting bracket

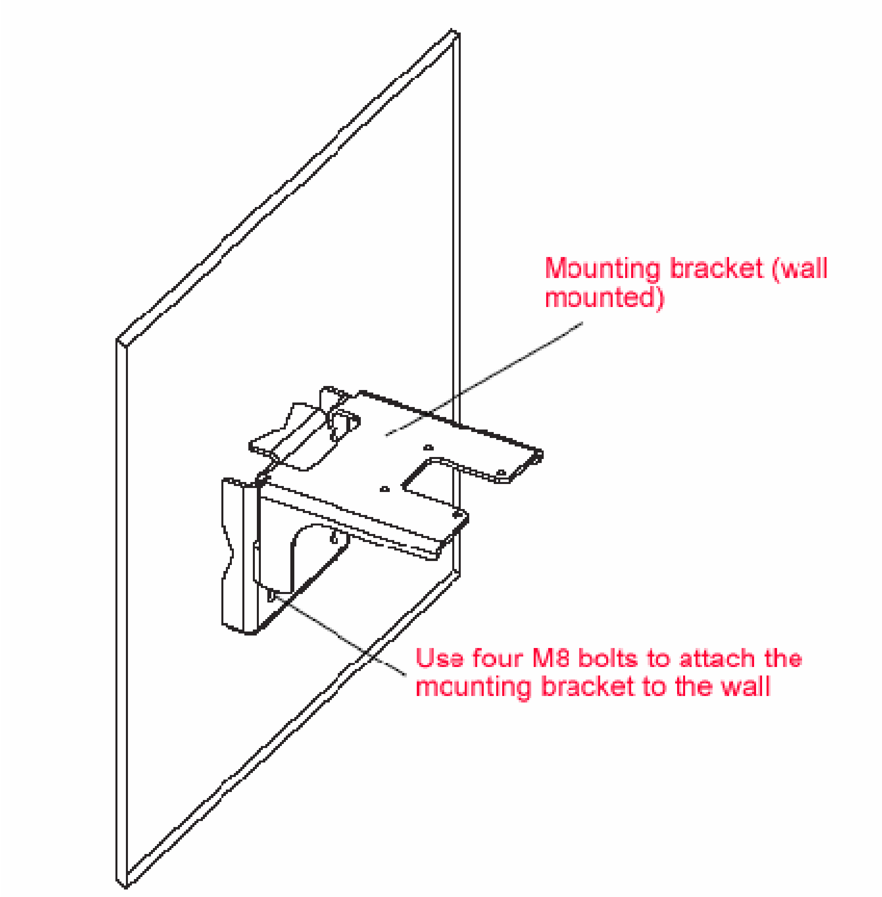


Figure 5: Wall mounting bracket for a transmitter

2.2.2. Mounting bracket for 2-inch tube

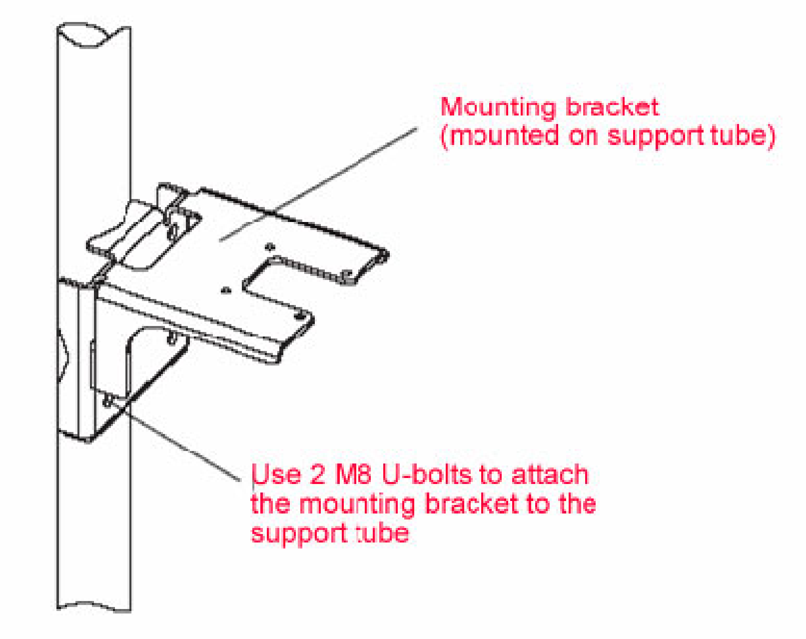


Figure 6: Mounting bracket for 2" tube for a transmitter

2.2.3. Mounting the transmitter on the mounting bracket

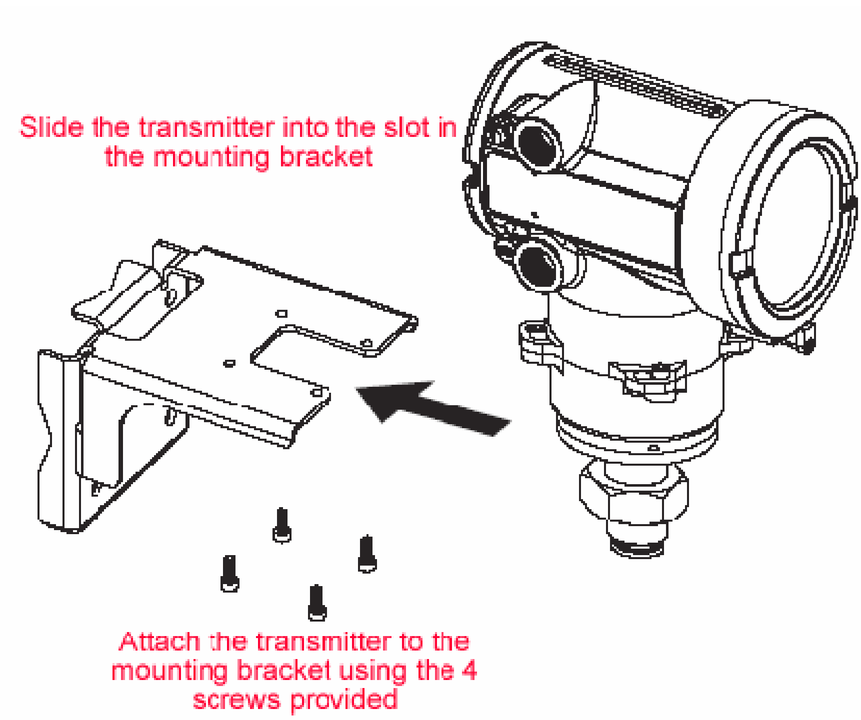


Figure 7: Mounting the transmitter on the mounting bracket

3. TUBING

3.1. REMINDER ON THREADS

3.1.1. Threads

3.1.1.1. British Standard Pipe (BSP) threads

These "Gas" profile threads are of two types:

- Parallel: they fit into the same parallel internal thread. The sealing is provided by an incorporated annular seal (or by a sealing washer).
- Taper: they fit into the same parallel or tapered internal thread. The sealing is provided by a precoating on the thread.

Thread designations

- **BSP Parallel (BSPP)**: G followed by the denomination, as per the ISO 228-1 standard. Example: a $^1/_8$ BSP parallel thread is written **G$^1/_8$**
- **BSP Taper (BSPT)**: R followed by the denomination, as per the ISO 7-1 standard. Example: a $^1/_8$ BSP taper thread is written **R$^1/_8$**
- **Internal threads**:
  - BSP parallel: G followed by the designation
  - BSP taper: Rc followed by the designation

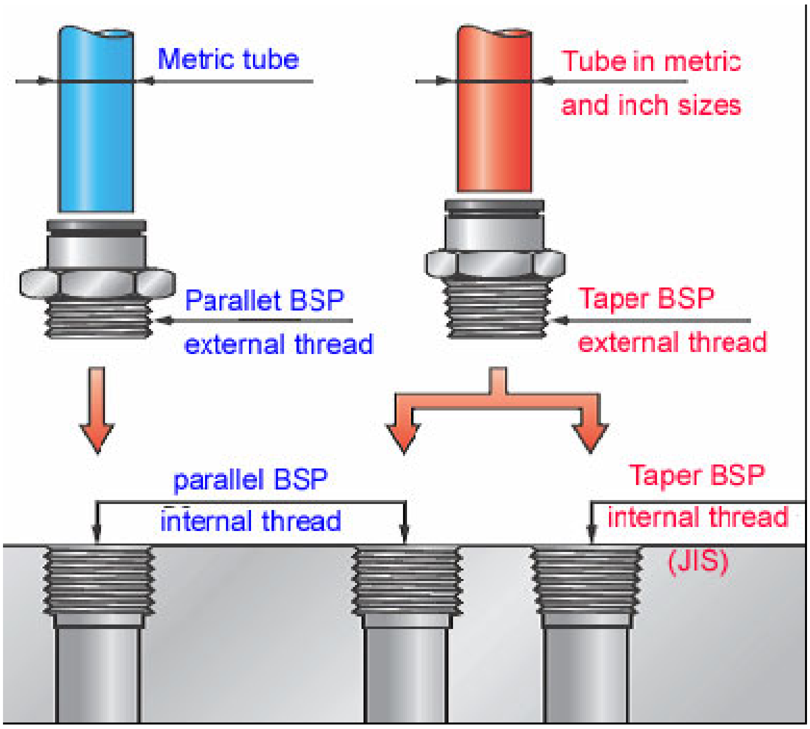


Figure 8: BSP threads

3.1.1.2. Metric threads

These ISO profile threads are parallel threads. They fit into the same parallel internal thread. The sealing is provided by an incorporated annular seal (or by a sealing washer).

Thread designations: M followed by the diameter and pitch values in millimetres, separated by the multiplication sign, as per the ISO 68-1 and ISO 965-1 standards.

Example: **M7x1**

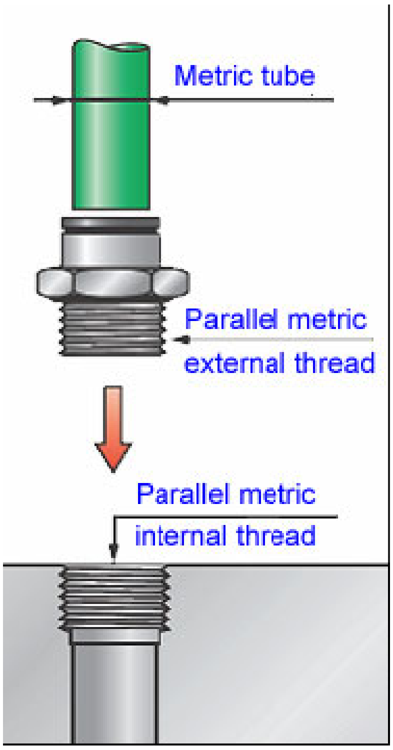
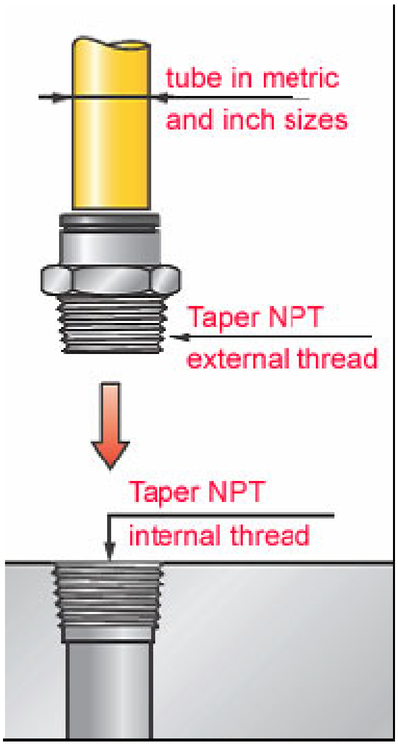


Figure 9: Metric threads

3.1.1.3. National Pipe Thread (NPT) threads

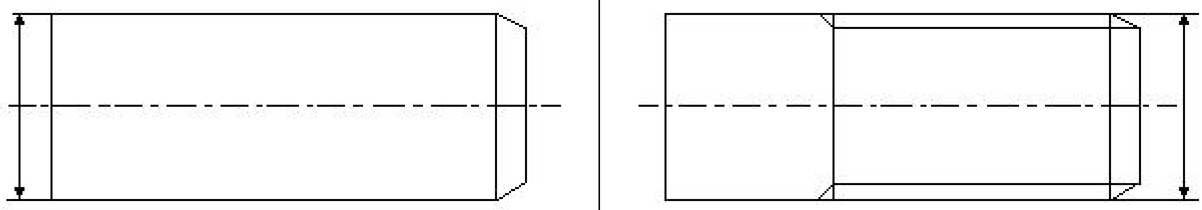


This is an American standard with taper threads. They fit into the same tapered internal thread. The sealing is provided by a precoating on the thread.

Figure 10: NPT threads

3.1.2. Definition of thread cutting using a threading die

Thread cutting is a manual machining process which involves the removal of metal chips. Its consists of cutting helical-shaped grooves in a previously calibrated cylindrical workpiece. The part at the end of the operation is a screw.



Initial state (calibrated cylinder) | Final state (screw)

Figure 11: Definition of the thread

3.1.2.1. Die (also called "threading die")

<u>Different types of dies:</u>

The die is in the form of a nut in which teeth are cut.

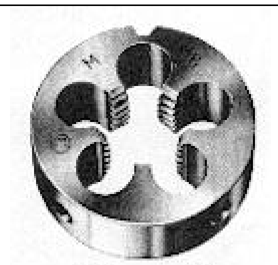
The types of dies depend on:

Pitch direction

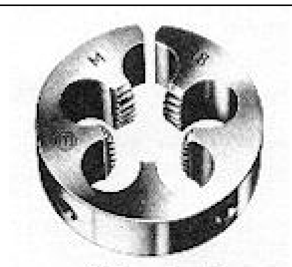
- right-hand dies
- left-hand dies

Pitch type

- fine pitch dies
- normal pitch dies



Closed circular die



Open circular die

Figure 12: Circular dies

Die stock

The die stock is a cage which holds the die. It has handles which facilitate its use.

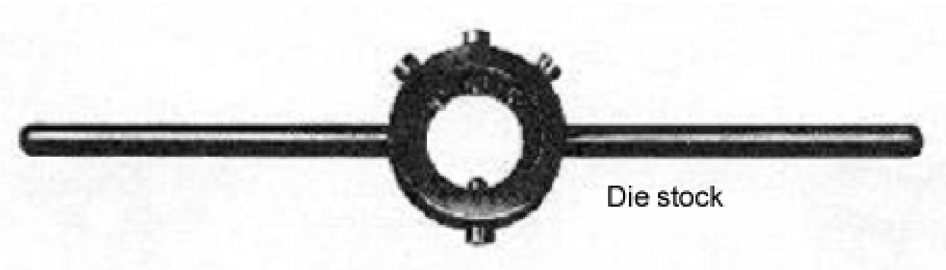


Figure 13: Die stock

3.1.2.2. Thread characteristics

A thread is characterised by:

- Profile (triangular, trapezoidal, round, gas)
- Pitch
- Thread direction
- Length

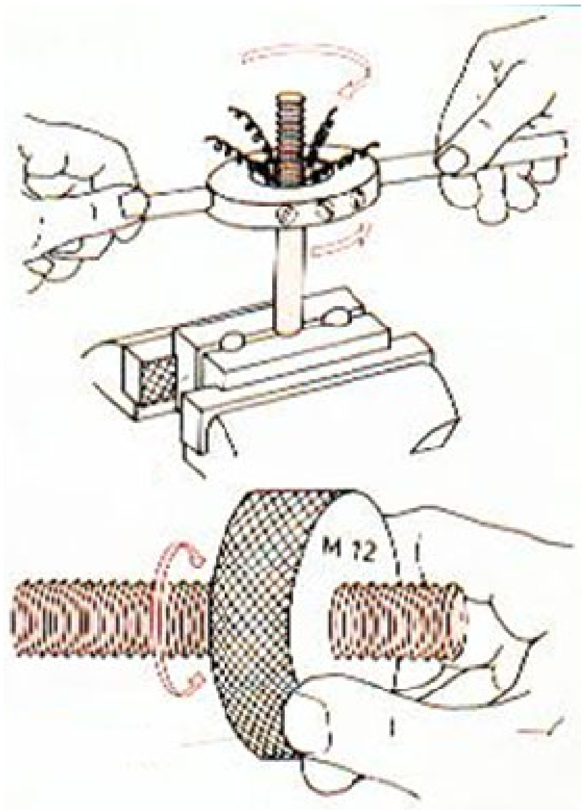
3.1.2.3. Standardised thread designation

The standardised thread designation consists of:

- System or profile
- Nominal diameter
- Pitch (distance between two consecutive thread crests)

Example: *M 10 X 1.5*

3.1.3. Procedure for making a thread



1. Engage the die.
2. Ensure that the die is the correct way round and that it is centred on the workpiece.
3. Lubricate with cutting oil.
4. Turn the die in the direction of the cutting (from left to right) to make the thread.
5. Reverse the movement from time to time to break the chips.

Figure 14: Making a thread

3.2. COMPRESSION COUPLINGS

This type of coupling is used to connect pipes made of Stainless steel or Carbon steel.

As their name indicates, compression couplings form a tight seal by applying a compression force to pipes and to the pipe coupling. The coupling is compressed against the pipe with sufficient force to eliminate all the space remaining in the joint, thus preventing fluid leaks.

The compression coupling consists of an external "compression nut" and an internal "ring" or "olive". When the nut is tightened it becomes fixed on the olive and makes it take the shape of the circumference of the pipe. The shape and the material of the olives can vary according to the pipe material. In order to function correctly, the olive must be the right way round. The olive is normally placed so that the longer inclined side is furthest away from the nut.

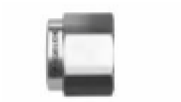
 *Nut*	 *Rear ring*	 *Front ring*

Figure 15 : Nuts and rings

The couplings produced by some manufacturers only have a single olive. On our sites we use "Swagelok" connections with 2 rings (front and rear).

All these couplings are those most commonly used. We will see in the next chapter how to connect our instrumentation tubes to these couplings.

The ring or olive couplings are the most reliable and the most solid I have met.

There are also plastic quick-connect couplings. As far as maintenance is concerned, they are not the best equipment since they can break in your hands because they very quickly deteriorate due to heat or to the sun's rays.

3.2.1. Straight couplings

3.2.1.1. Male union

Figure 16: Male union

3.2.1.2. Female union

Figure 17: Female union

3.2.1.3. Male end fitting

Figure 18: Male end fitting for tube

3.2.1.4. Equal union

Figure 19: Equal union fitting

3.2.1.5. Piping penetration

Figure 20: Piping penetration

The "***piping penetration***" coupling is very practical when you want to get air into a box (e.g. distributor box).

3.2.2. 45° elbow couplings

Figure 21: 45° elbow coupling

3.2.3. 90° elbow couplings

3.2.3.1. Union elbow

Figure 22: 90° union elbow

3.2.3.2. Male elbow coupling

Figure 23: 90° male elbow coupling

3.2.3.3. Female elbow coupling

Figure 24: 90° female elbow coupling

3.2.4. Tees

3.2.4.1. Union Tee

Figure 25: Union Tee

3.2.4.2. Male Tee

Figure 26: Male Tee

3.2.4.3. Female Tee

Figure 27: Female Tee

3.3. QUICK-CONNECT COUPLINGS

This type of coupling is used to connect metric plastic tubes.

The tube must be pushed fully home in the coupling.

It provides instant connection and sealing.

- To disconnect it, push the external button and pull the tube.
- Use a tube cutter for a good, straight cut

3.3.1. Straight coupling

Figure 28: Straight quick-connect coupling

3.3.2. Elbow couplings

3.3.2.1. 90° elbow couplings

Figure 29: 90° elbow quick-connect coupling

3.3.2.2. 45° elbow couplings

Figure 30: 45° elbow quick-connect coupling

3.3.3. Tees

Figure 31: Quick-connect tees

4. CONNECTING INSTRUMENTATION TUBES TO COMPRESSION COUPLINGS

Before inserting the tube in the coupling and tightening the nut on the ring, the ring must be precrimped on the tube.

To do this we have a very practical tool called a "precrimping tool"

4.1. PRECRIMPING THE TUBE

The "precrimping tool" is shown in the figure

Figure 32: Tube precrimping tool

We will now use the following examples to illustrate the procedure.

Firstly, we place the nut and the ring on the tube

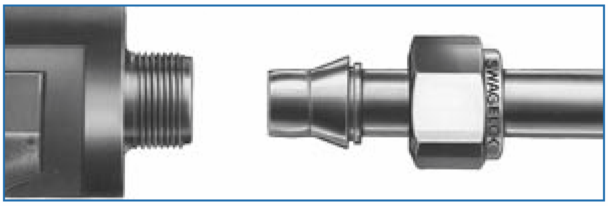


Figure 33: Insertion of the tube in the precrimping tool

The tube must then be inserted in the precrimping tool. We ensure that it firmly abuts on the shoulder of the crimping tube and we hand tighten the nut

We maintain the body of the precrimping tool and tighten the nut almost two turns with a spanner.

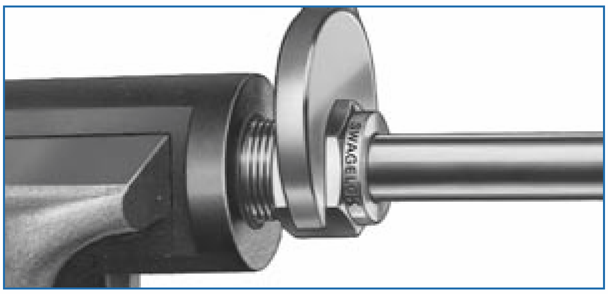


Figure 34: Crimping the tube in the tool

And finally, we can:

- Unscrew the nut
- Remove the tube with the precrimped rings from the tools.

Once the tube has been precrimped we can insert our tube with its precrimped ring into the coupling we wish to connect.

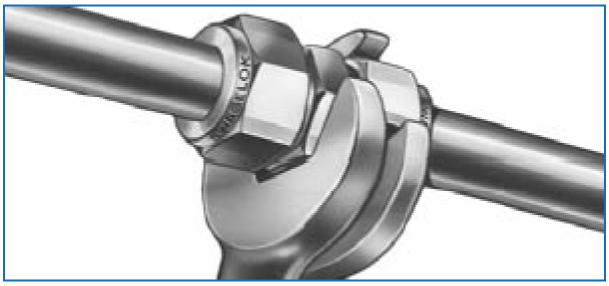


Figure 35: Insertion of the crimped tube into a coupling

Furthermore, it is essential for the integrity of the coupling that ***we do not apply excessive force when tightening the nut***. If the connection is too tight, the olive will become distorted resulting in leaks.

Excessive tightening is the main cause of leaks in compression couplings.

As a general rule, a compression coupling must initially be hand tightened, then tightened a quarter turn with a spanner. The coupling must then be tested and if we observe a slight seepage, the coupling must be slowly tightened a little more until the seepage stops.

If during assembly and disassembly of these couplings you hear a squeaking noise when tightening with a spanner, it is too late, the coupling has been destroyed. The only solution is to replace it.

4.2. SEALING OF COUPLINGS

Here is a short reminder because, on worksites, I have already seen instrument technicians connect instruments to couplings without using Teflon.

This is important because it can result in large measurement errors if there are leaks on the instrumentation couplings.

Here is the procedure to be followed to apply Teflon on all types of couplings:

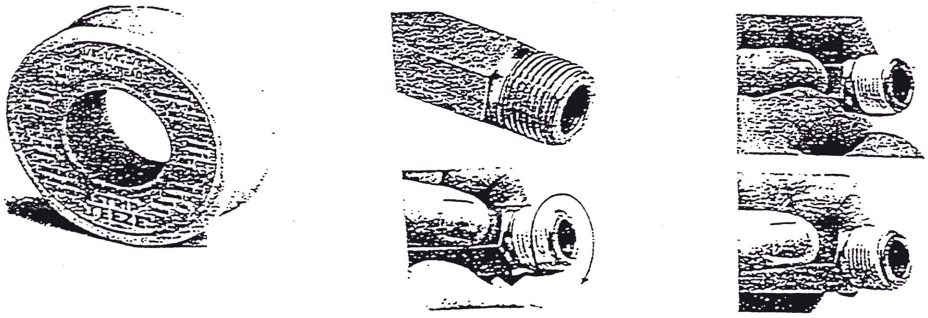


Figure 36: Application of Teflon (PTFE) on all couplings

The Teflon tape must be applied in the opposite direction to the thread.

"***Loctite***" is now also used to replace Teflon but I would not recommend it because the couplings become difficult to remove.

Figure 37: "Loctite" for sealing the couplings

4.3. INSTRUMENTATION TUBES

4.3.1. Instrumentation tubing specifications

Remember that to connect transmitters to the process the pipes must not exceed ½ inch in diameter. 75% of the time the transmitters are connected using ***couplings with NPT threads***.

The following tables show all the types of tube connections, the diameters are given for each component according to the piping class (the class is the ***rating***).

ASSEMBLY TYPE: Thinwall tubing and compression fittings

BASE MATERIAL: Stainless steel

PROCESS CONDITIONS:

150 #, 300 #, 600 #
(and 900 #, 1500 # production water P < 200 barg)

PRESSURE AND TEMPERATURE FOLLOWING ANSI B 16.5

COMPONENT	SIZE	RATING	CONNECTION	TYPE	PACKING BOX MATERIAL	REFERENCE STANDARDS Non marine atmosphere	REFERENCE STANDARDS Marine atmosphere	NOTES
INSTRUMENT BALL VALVE	1/4" to 3/4"	3000 psig	OD	Ball type; end entry; full bore; forged SS 316L body; SS 316 ball; ball seals: Viton O-rings	Graphite	AISI F 316L	AISI F 316L	1
INSTRUMENT PLUG VALVE	1/4" to 1/2"	3000 psig	OD	Forged SS 316L body, Non-rotating stem.	Graphite	AISI F 316L	AISI F 316L	
INSTRUMENT GAUGE VALVE	1/2"	6000 psig	Inlet 1/2" NPT(M) Outlet 1/2" NPT(F)	Bar stock SS 316L body x 1 male inlet x 3 female outlets	Graphite	AISI F 316L	AISI F 316L	
INSTRUMENT COMPACT MANIFOLD	1/2"	6000 psig	NPT	With bypass, 3 or 5-valve, with or without drains, 1/2" NPT female inlets, fixed flanged or 1/2" NPT female outlets	Graphite	AISI F 316L	AISI F 316L	1
FLANGE	3/4"	According to Piping Class	Threaded 3/4" NPT	Flange to compression fitting connector Flange and gasket type and material according to Process Piping Class		ANSI B16.5	ANSI B16.5	1
FITTING	1/4" to 3/4"			For thinwall tubing, of forged SS, twin ferrule compression-type, Swagelok or Gyrolok style		AISI F 316L	AISI F 316L	1
UNION	1/4" to 2"	3000 psig	NPT	3 parts, forged SS		AISI F 316L	AISI F 316L	1
PLUG / CAP	1/4" to 1"	3000 psig	NPT	Forged SS		AISI F 316L	AISI F 316L	1
TUBE	1/4" to 1" 1/2	Sch. 80S to Sch. 160S		Seamless drawn SS		AISI TP 316L	AISI TP 904	1, 3
THINWALL TUBING	1/4" OD to 1/2" OD	0.049" thick		Seamless drawn SS		AISI TP 316L	AISI TP 904	2

ASSEMBLY TYPE:	1/2" Sch. 160S pipe with threaded fittings				PROCESS CONDITIONS: 900#, 1500# PRESSURE AND TEMPERATURE FOLLOWING ANSI B 16.5			
BASE MATERIAL:	Stainless steel							
COMPONENT	**SIZE**	**RATING**	**CONNECTION**	**TYPE**	**PACKING BOX MATERIAL**	**REFERENCE STANDARDS** Non marine atmosphere	 Marine atmosphere	**NOTES**
INSTRUMENT BALL VALVE	**1/2"**	**1500#**	**SW**	Ball type; end entry; full bore; forged SS 316L body; SS 316 ball; ball seals: Viton O-rings	Graphite	AISI F 316L	AISI F 316L	1
INSTRUMENT PLUG VALVE	**1/2" to 3/4"**	**5000 API**	**NPT**	Needle valve; Y shaped SS 316 body, 1/2" male in, 1/2" female out (Kerotest type); steel needle, seat seal F6	Graphite	AISI F 316L	AISI F 316L	1, 2
INSTRUMENT GAUGE VALVE	**1/2" to 3/4"**	**6000 psig**	**Inlet 1/2" NPT(M)** **Outlet 1/2" NPT(F)**	Bar stock SS 316L body x 1 male inlet x 3 female outlets	Graphite	AISI F 316L	AISI F 316L	1
INSTRUMENT COMPACT MANIFOLD	**1/2"**	**6000 psig**	**NPT**	With bypass, 3 or 5-valve, with or without drains, oval flanges inlets, fixed flanged outlets	Graphite	AISI F 316L	AISI F 316L	3
FLANGE	**3/4"**	**900# to 1500#**	**Outlet 3/4" OD**	Flange to compression fitting connector Flange and gasket type and material according to Process Piping Class		ANSI B16.5	ANSI B16.5	7
FITTING	**1/2"**	**3000 psig or 6000 psig**		Forged SS		AISI F 316L	AISI F 316L	1, 6
UNION	**1/2"**	**3000 psig or 6000 psig**		2 or 4 bolt forged SS flanges, tapered seat, lapped seals, integral seat		AISI F 316L	AISI F 316L	5
PLUG / CAP	**1/4" to 1"**	**3000 psig or 6000 psig**	**NPT**	Forged SS		AISI F 316L	AISI F 316L	1
TUBE	**1/2**	**Sch. 160S**		Seamless drawn SS		AISI TP 316L	AISI TP 904	1, 4
THINWALL TUBING	**1/4" OD to 1/2" OD**	**0.049" thick mini**		Seamless drawn SS thickness > 0.049" according to P and T		AISI TP 316L	AISI TP 904	8

Note:

NPT (National Pipe Thread) is an American standard for taper threads (NPT) and NPS (Nominal Pipe Size) for straight threads for connecting piping and couplings. The ANSI/ASME B1.20.1 standard covers 60 degree NPS threads with flat thread crest for sizes from 1/16 inch to 24 inches. The taper angle for all NPT threads is 3/4 inch per foot. The 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1 1/4, 1 1/2 and 2 inch sizes are frequently used on pipes and couplings produced by most American suppliers.

Smaller sizes are sometimes used for compressed air. Larger sizes are rarely used because other connection methods are more practical above 3 inches in most applications.

NPS threads are not tight in the internal diameter of the pipe (Schedule 40). Due to the pipe wall thickness the real thread diameter is greater than the NPS threads, and considerably greater for small NPS threads.

Other pipe schedules have a different wall thickness but the outer diameter (OD) and the thread profile remain the same and therefore the internal diameter of the pipe is different to the nominal diameter.

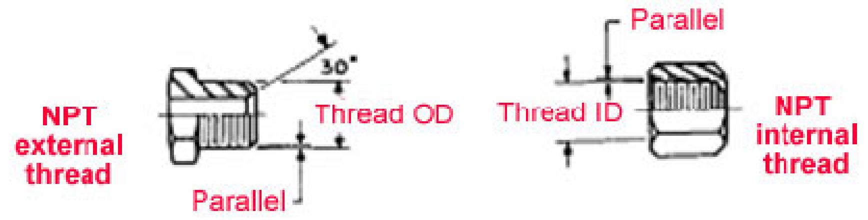


Figure 38: Diagram of NPT coupling with internal and external threads

4.3.2. Polyamide tube

Polyamide tubes are increasingly used today and are replacing copper tube for instrument air or gas supply.

They are obviously quicker and easier to replace when worn than copper.

Figure 39: Polyamide tube

This type of tube can resist a pressure of up to **14 bars** and a temperature of **70°C**.

The diameters most commonly used for instrumentation are **4/6 mm**, **6/8mm**, **8/10mm or even 10/12mm**.

The diameters of these tubes are **internal diameter/outer diameter**.

4.3.3. Copper tube

See the engineering course on "Piping".

5. THE DIFFERENT CABLES USED IN INSTRUMENTATION

5.1. WHAT IS A CABLE MADE OF?

Cables are intended to transport electric current. They must be able to fulfil this role safely with respect to equipment and personnel.

Cables generally consist of three main parts:

- Conductor
- Insulation
- Mechanical protection

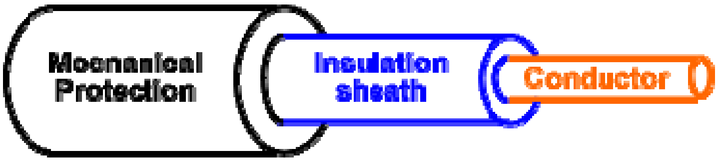


Figure 40: Construction of a 'standard' cable

The conductor transports electric energy. Several conductors sharing the same cable will be separated and isolated from each other.

Should the mechanical protection be damaged, the insulation (if the insulation sheath is not damaged) must not be affected. In this case, the insulation sheath is the only effective protection and it also provides mechanical protection.

5.1.1. The conductor

The conductor must have a low resistivity (low resistance), this characteristic is provided by certain metals.

The conductor must also have other physical properties. It must be ductile and flexible. A ductile metal may be pulled and drawn without breaking, this is a basic quality which is required when manufacturing cables. However, there are other factors that a manufacturer (or a user) requires of a cable,these concern the weight and cost. Silver is thus one of the best conducting metals but it is easy to understand why copper conductors are preferred.

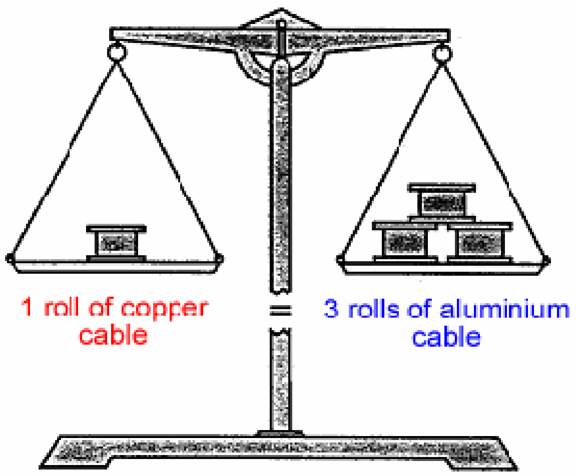


Figure 41: Cu conductor/Al conductor

Aluminium is also increasingly used as a metal conductor. Aluminium has a resistivity 1.6 times greater than copper, and the same current therefore requires a larger cross-sectional area, however aluminium is (far) less expensive and much lighter, (*you can clearly feel the difference when you pull the cables).*

5.1.2. The insulation

5.1.2.1. Properties

The main function of the insulation on the conductive core of a cable is to "prevent the electricity from escaping" from the cable in question, and to prevent any external contact with a live part (i.e. a person touching the conductor).

The insulation is required to be flexible, to support differences in temperature and resist mechanical constraints and external attack. The main property required is however high electric (or dielectric) resistance (or resistivity).

The insulation of an electrical energy transport cable must have the following properties

- High electric resistance
- A certain amount of flexibility
- Resistance to temperature changes
- Mechanical resistance to impact and external aggression (chemical, atmospheric, etc.)

5.1.2.2. Insulation material

PVC is the most commonly used material. *PVC is the abbreviation for Polyvinyl chloride.*

The principal advantages of PVC are:

- Good insulating quality (high resistance)
- Waterproof
- Low cost
- Easy to colour
- Good mechanical strength

The main disadvantages of PVC are:

- Softens above 70°C
- Becomes brittle below 0°C3

Some qualities of PVC can resist temperatures of up to 85°C, but most remain within the range indicated above (0 - 70°C)

The other materials used as cable insulations are, among others:

- Vulcanised rubber
- Synthetic rubber
- Silicone (derived from silicon)
- Paper (treated with resin)

Paper insulation was used in HV cables but has now been replaced by synthetic rubber for almost all applications. It is however still used in some flexible cables where a high flexibility is required.

Synthetic rubbers are used for high or low temperatures.

Silicone is used for very high temperatures, i.e. approximately 150°C.

5.1.3. Mechanical protection

The main function of the mechanical protection is to prevent damage to the conductive core's insulation, which could cause electrocution, sparks or start a fire.

The cable sheath

The sheath is the cable's mechanical protection.

The type of cable shown is used to connect bedside lamps or your washing machine, fridge, etc.

Most cable protective sheaths are made of PVC; rubber is used for cables requiring extra flexibility. This type of cable is mainly used for domestic distribution, and in tertiary applications and offices where there little risk of mechanical damage.

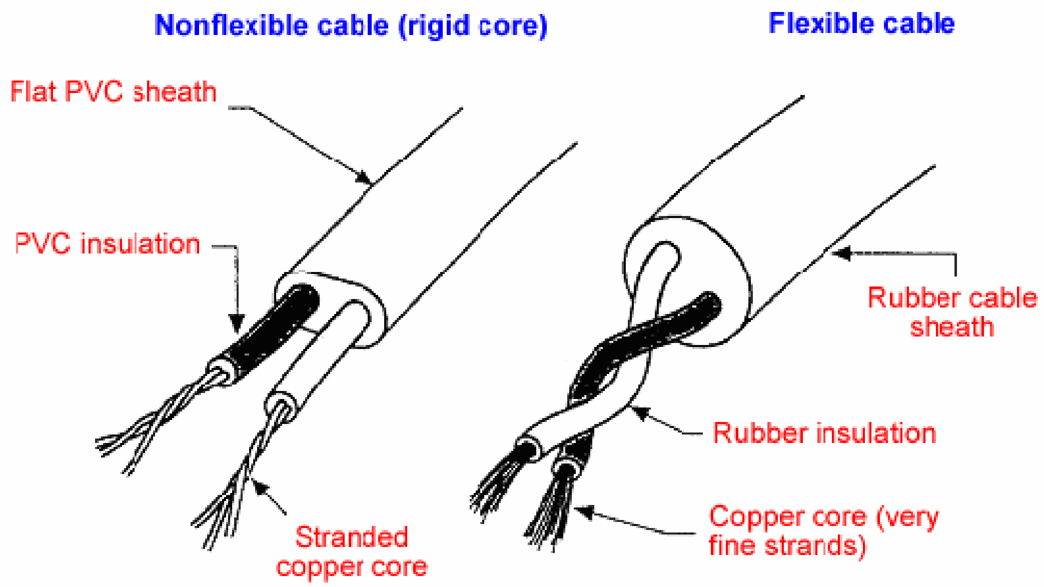


Figure 42: Different cable sheaths (mechanical protection)

This paragraph gives a general description of the composition and manufacture of cables. We will consider other types of mechanical protection later on.

5.1.4. Sheathed cables

These are the cables which you see "lying around" at home, in stores, in the office, or even on worksites (during construction). This is the cheapest and quickest means of laying cables. The cables are protected by their own sheaths only, thus providing ***minimal mechanical protection***.

Most sheathed cables have an external PVC sheath which may also be made of:

- Synthetic or natural rubber
- Agglomerate PVC
- Braid (metal or other)

The 3 cable types shown correspond to:

a) a stranded core conductor

b) a rigid core conductor with ground (earth) wire

c) three rigid core conductors with a fourth ground conductor

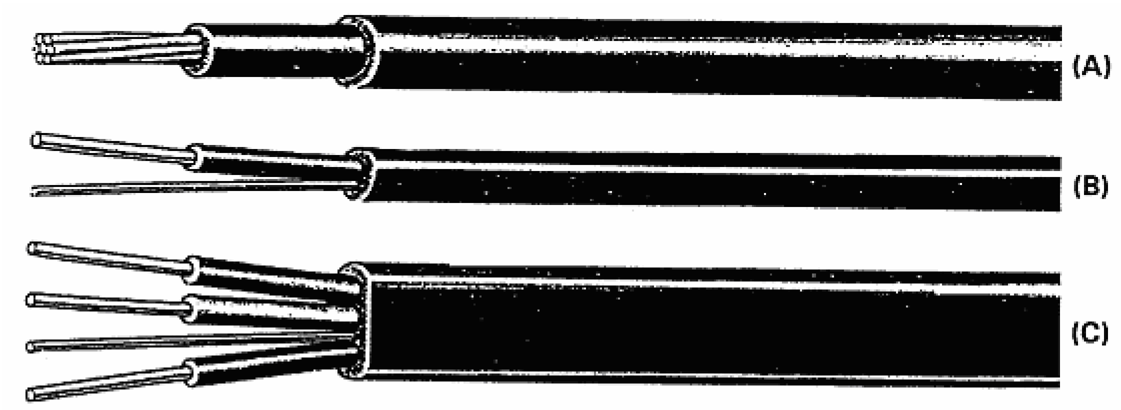


Figure 43: Different PVC sheaths

5.1.5. Armoured cables

The cables are mechanically protected by a steel armour if there is a risk of attack (impact, compression, rodents, etc.).

This is the type of cable which is frequently installed in our industry due to the permanent risk of mechanical damage.

The conductors and their insulation are protected by a metal or even plastic sheath, armour or braid (term as applicable). A cable may have several sheaths/armoured coverings. However, this additional mechanical protection more generally consists of steel wire armour (SWA) as shown in the figure.

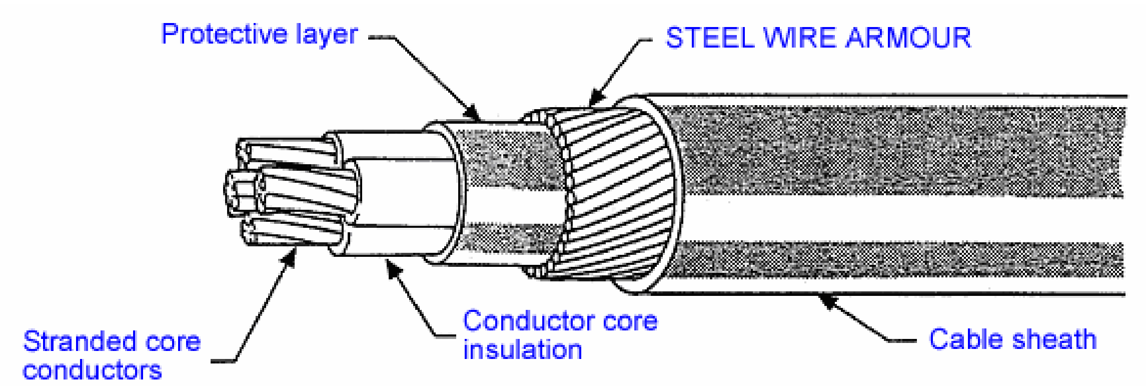


Figure 44: Steel wire armoured (SWA) cable

The armour may also consist of

- A helically-wound steel tape.
- An aluminimum tape (or sheath)

These armoured cables may be installed directly in contact with equipment and/or laid in cable trays, trenches, conduits, etc.

5.1.6. Mineral-insulated cables

These cables have a mechanical protection which consists of a metal sheath, which is why it is specified in their designation: *mineral insulated and metal sheathed cables*. These types of cables can be found in our industry with "fire resistant cables", i.e. cables used to resist fire in safety circuits and areas where there is a risk. In the instrumentation field, we use them as thermocouple cables installed in various environments

There are two types of metal sheaths:

- Mineral Insulated Copper Sheath (MICS).
- Mineral Insulated Aluminium Sheath (MIAS)

The conductors in this type of cable are insulated at high pressure using magnesium oxide powder

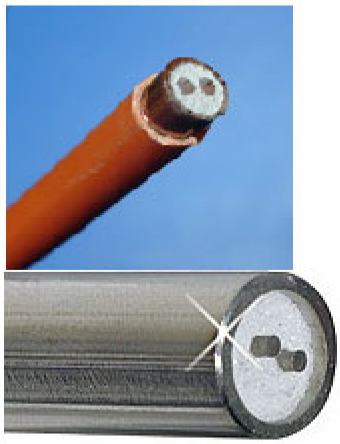


Figure 45: Cross section of high temperature resistant cables

These cables generally have an additional PVC sleeve over the metal sheath to protect against corrosion and provide good resistance to damp atmospheres. These cables are connected using special cable glands to avoid the moisture entering the cable.

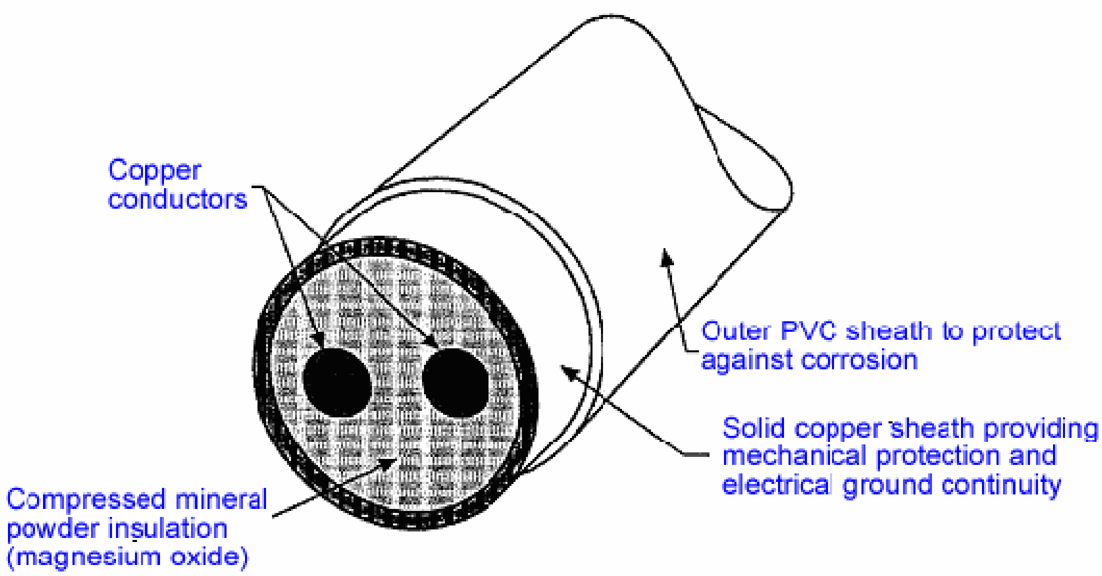


Figure 46: Construction of a mineral-insulated cable

5.2. TRANSMITTER POWER SUPPLY CABLES

'G' for ground (earth) indicates that one of the conductors has a green and yellow coloured insulation. E.g.: 3G1.5 which indicates a cable with 3 x 1.5 mm² conductors (one of which is a yellow/green conductor)

5.2.1. Cable U1000 R2V

Figure 47: Conventional cable U1000 R2V

These cables are designed for normal use in industry and are particularly recommended in fixed low voltage energy distribution installations. Multi-conductor cables are well-adapted to remote command and control installations. When there is a risk of chemical attack (corrosion) or prolonged immersion, use **1000 RGPFV**. When there is a high ambient temperature, apply the correction factor.

5.2.1.1. Installation

These cables can be used in cable trays, channels and troughs or fixed to the walls. They can be buried if they have additional mechanical protection.

Minimum bend radius

For fixed installation: 6 times the external diameter. During installation, this value must be doubled.

5.2.1.2. Identification of conductors

- 2 conductors: blue + brown
- 3 conductors = Y / G + blue + brown or brown + black + grey

5.2.1.3. Electrical characteristics

Number of conductors Cross-sectional area (mm²)	Admissible current (A)		ΔU (cosφ 0.8) V/A.km	External diameter (mm)			Weight (kg/km)
	Buried	Open air		Core	Min.	Max.	
1 x 1.5	31	24	24.8	1.37	-	6.4	48
1 x 2.5	41	33	15.3	1.76	-	6.8	60
1 x 4	53	45	9.2	2.23	-	7.2	78
1 x 6	66	58	6.4	2.90	-	8.2	102
1 x 10	87	80	3.7	3.70	-	9.2	146
1 x 16	113	107	2.4	4.80	-	10.5	207
1 x 25	144	138	1.40	6.24	-	10.92	302
1 x 35	174	169	1.00	7.38	-	12.06	398
1 x 50	206	207	0.78	8.10	-	12.76	514
1 x 70	254	268	0.56	9.80	-	14.66	724
1 x 95	301	328	0.43	11.30	-	16.36	975
1 x 120	343	382	0.36	12.70	-	17.96	1219
1 x 150	387	441	0.31	14.10	-	19.96	1485
1 x 185	434	506	0.26	15.70	-	21.96	1844
1 x 240	501	599	0.22	18	-	24.66	2373
1 x 300	565	693	0.19	20.10	-	27.16	2957
1 x 400	662	825	0.17	23.50	-	31.36	3846
1x 500	750	946	0.15	27.1	-	35.36	4872
1 x 630	850	1088	0.14	30.15	-	39.21	6266
2 x 1.5	37	26	24.8	1.37	8.8	10.5	129
2 x 2.5	48	36	14.8	1.76	9.6	11.5	162
2 x 4	63	49	9.2	2.23	10.5	13.0	209
2 x 6	80	63	6.2	2.90	11.5	14.0	282
2 x 10	104	86	3.7	3.70	13.0	16.0	397
2 x 16	136	115	2.4	4.80	15.0	18.5	553
2 x 25	173	149	1.3	6.24	17.5	21.02	900
2 x 35	208	185	1.15	7.38	19.5	23.35	1167
3 G / x 1.5	31	23	24.8	1.37	9.2	11.0	130
3 G / x 2.5	41	31	14.8	1.76	10.0	12.5	170
3 G / x 4	53	42	9.2	2.23	11.0	13.5	230
3 G / x 6	66	54	6.2	2.90	12.0	15.0	310
3 G / x 10	87	75	8.7	3.70	13.5	17.0	460
3 G / x 16	113	100	2.4	4.80	15.5	16.5	660
3 G / x 25	144	127	1.37	6.24	19.0	22.39	1117
3 x 35	174	158	1.00	7.38	21.0	24.9	1464

Table 1: Electrical characteristics of cable U1000 R2V

5.2.2. Flexible core cable HO7RN-F

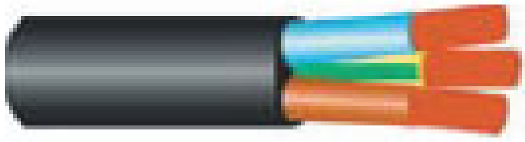


Figure 48: Cable HO7 RN-F

This cable is particularly well adapted as a power supply cable for mobile site equipment, electric tools and construction worksites. It can be used up to 0.6/1KV for protected fixed installations and as power supply cable for motors for lift equipment and similar equipment.

5.2.2.1. Installation

Cable designed to operate out of doors. When it is buried, provide a mechanical protection (trough, conduit, etc.).

Bend radius

In use: 6 to 8 times the external diameter of the cable. In static use: 3 times the external diameter.

5.2.2.2. Identification of conductors

- 1 conductor = black
- 2 conductors = blue + brown
- 3 conductors = Y/G + blue + brown

5.2.2.3. Electrical characteristics

Number of conductors Cross-sectional area (mm²)	Admissible current (A)	ΔU (cosφ 0.8) V/A.km	External diameter (mm)			Weight (kg/km)
			Core	Min.	Max.	
1 x 1.5	23	23.3	1.5	5.7	7.1	50
1 x 2.5	32	14.0	1.9	6.3	7.9	66
1 x 4	43	8.7	2.5	7.2	9.0	94
1 x 6	56	5.9	3.0	7.9	9.8	109
1 x 10	77	3.4	3.8	9.5	11.9	182
1 x 16	102	2.2	5.0	10.8	13.4	256
1 x 25	136	1.4	6.3	12.7	15.8	369
1 x 35	168	1.04	7.6	14.3	17.9	482
1 x 50	203	0.75	9.0	16.5	20.6	662
1 x 70	254	0.56	10.8	18.6	23.3	895
1 x 95	315	0.44	12.7	20.8	26.0	1160
1 x 120	363	0.36	13.9	22.8	28.6	1430
1 x 150	416	0.31	15.9	25.2	31.4	1740
1 x 185	475	0.28	17.7	27.6	34.4	2160
1 x 240	559	0.23	19.4	30.6	38.3	2730
1 x 300	637	0.20	23.0	38.5	41.9	3480
1 x 400	746	0.18	26.0	37.4	46.8	4510
1x 500	833	0.16	30.0	41.3	52.0	5700
2 x 1	18	39.4	1.3	7.7	10.0	99
2 x 1.5	23	27.0	1.5	8.5	11.0	111
2 x 2.5	32	16.2	1.9	10.2	13.1	161
2 x 4	43	10.1	2.5	11.8	15.1	238
2 x 6	56	6.7	3.0	13.1	16.8	279
2 x 10	77	3.8	3.8	17.7	22.6	538
2 x 16	102	2.5	5.0	20.2	25.7	744
2 x 25	136	1.68	6.3	24.3	30.7	1074
3 G 1	18	39.4	1.3	8.3	10.7	117
3 G 1.5	23	27.0	1.5	9.2	11.9	134
3 G 2.5	32	16.2	1.9	10.9	14.0	195
3 G 4	43	10.1	2.5	12.7	16.2	290
3 G 6	56	7.0	3.0	14.1	18.0	346
3 G 10	77	4.0	3.8	19.1	24.2	663
3 G 16	102	2.5	5.0	21.8	27.6	924
3 G 25	136	1.7	6.3	26.1	33.0	1345
3 G 35	168	1.21	7.6	29.3	37.1	1760
3 G 50	203	0.87	9.0	34.1	42.9	2390
3 G 70	262	0.64	10.8	38.4	48.3	3110
3 G 95	320	0.50	12.7	43.3	54.0	4170
3 G 120	373	0.40	13.9	47.4	60.0	5080
3 G 150	432	0.35	15.9	52.0	66.0	6220

Table 2: Electrical characteristics of cable HO7 RN-F

5.3. INSTRUMENTATION CABLES

5.3.1. Meaning of instrumentation cable coding

Instrumentation cables covered by the NF M 87-202 standard are used in the oil industry to transmit AC or DC analogue signals.

They are of the PVC/PVC type and can be non armoured, armoured or lead-sheathed armoured.

- Non armoured cables are used when there is no risk of mechanical deterioration.
- Armoured cables are used when there is a risk of mechanical deterioration.
- Lead-sheathed armoured cables are used when there is a risk of contact with aromatic hydrocarbons.

Meaning of the code consisting of 5 series of 2 figures or letters:

- 1st series = number of pairs, triplets or quads: **01** to **27**
- 2nd series = pair (**IP**), triplet (**IT**), quad (**IQ**)
- 3rd series = conductive core **05** (1 wire 0.8 mm) or **09** (7 wires 0.4 mm) or **15** (7 wires 0.52 mm)
- 4th series = general screen (**RG**), individual screen + general screen (**EI**)
- 5th series = mechanical protection: non armoured (**SF**), with armour (**FA**), with lead + armour (**PF**)

5.3.2. Conductor standard colours

- 1 pair: white - red
- 1 triplet: white - red - blue
- 1 quad: white - red - blue - yellow

5.3.3. Construction of an instrumentation cable

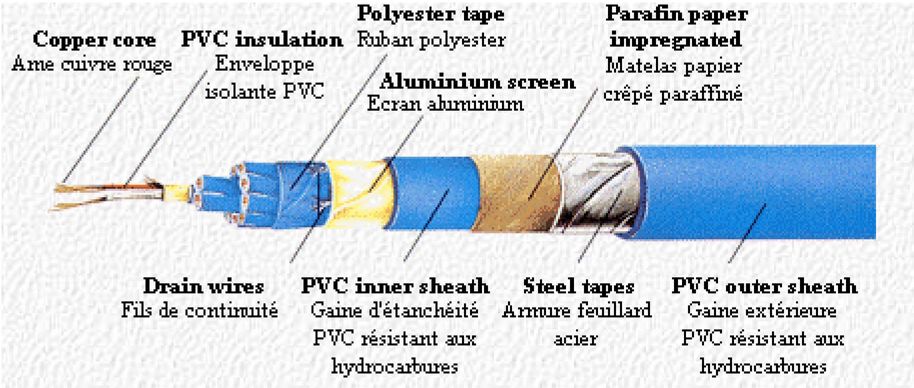


Figure 49: Exploded view of an instrumentation cable

- **Core:** Central metal part of a conductor (*copper core*) which can be:
    - ***solid***: a single wire
    - ***stranded core***: formed of several strands twisted together into one or more larger strands. Depending on the number of strands, the core is said to be ***rigid*** or ***flexible***.
- **Screen**: Individual screen (if applicable) and general screen (*polyester tape + aluminium screen*): Al/polyester tape with tinned copper drain strand (7x0.20 mm)
- **Sheath**: Lead in the presence of aromatic hydrocarbons (*PVC outer sheath*)
- **Insulation**: Insulating material (*PVC insulation*) surrounding the core of a conductor and designed to insulate it.
- **Armour**: Central part providing the mechanical protection for the conductors (*steel tapes*). Consisting of steel tapes or steel wires spirally wound around the cable, above the sheath and generally with a protective layer (paraffin-impregnated paper) between them.
- **Drain wires**: For electrical continuity.
- **Mechanical protection**: Grey (where applicable) PVC, PVC-HR oversheath (*PVC inner sheath*)

5.3.3.1. Conductor core

The core must satisfy the following conditions:

- ***Good conductivity*** to reduce losses when transporting energy. The materials must therefore be carefully chosen (maximum values of ρ)
  - copper: ρ = 18.51 mΩ.mm²/m at 20°C
  - aluminium: ρ = 29.41 mΩ.mm²/m at 20°C
- ***Mechanical strength*** sufficient to prevent the conductor breaking under the forces applied during installation, attachment and tightening of the conductors.
- Good ***flexibility*** to simplify the transit of the conductors in the conduits, to keep to the piping route, and to supply the mobile equipment.
- Good ***corrosion resistance*** due to atmospheric agents and chemical agents.
- Good ***reliability*** of the ***connections*** due to a good resistance to the physico-chemical effects of the contacts.

The standard defines a range of nominal cross-sectional areas for the conductor cores and divides them into four classes ***in order of flexibility***.

- Class 1: solid and rigid
- Class 2: rigid, stranded
- Class 5: flexible
- Class 6: flexible *(or flexible '+', e.g. used for arc welding cables, or cables on coiling units)*

Nominal cross-sectional area (mm²)	Conductor cores Number of stands x strand diameter in mm	
	Class 1	Class 2
1.5	1 x 1.38	7 x 0.50
2.5	1 x 1.78	7 x 0.67

Nominal cross-sectional area (mm²)	Conductor cores Number of stands x strand diameter in mm	
	Class 5	Class 6
0.5	16 x 0.20	28 x 0.15
0.75	24 x 0.20	42 x 0.15
1	32 x 0,20	56 x 0.15
1.5	30 x 0.25	85 x 0.15
2.5	50 x 0.25	140 x 0.15

Table 3: Construction of conductor cores

5.3.3.2. Insulation

This insulation must provide a good insulation for the conductor core and have the following properties:

- ***General properties for good insulation***
    - high resistivity
    - excellent dielectric strength
    - low electric losses
- ***Specific properties for the use of conductors and cables***
    - Good resistance to aging
    - Good resistance to cold, heat and fire
    - Not sensitive to vibrations and impacts
    - Good reactions in case of attack by chemicals

<u>Main materials:</u>

- **Thermoplastic materials**

  The temperature causes a reversible variation in plasticity. This applies for:

    - Polyvinyl chloride (PVC) which is frequently used due to its good electrical and mechanical properties and its resistance to cold, heat aging, water and commonly-used chemicals and to flame spread. However, the combustion of this substance involves the emission of toxic and corrosive products.
    - Polythene (PE), whose remarkable properties make it a preferred insulation material (particularly for HV). The combustion of this material does not involve the emission of toxic or corrosive products.

- **Cross-linked elastomers and polymers**

  They are elastic, i.e. able to accept major deformations. This applies for:

    - Cross-linked polythene (PR), mainly used for temporary overloads and unfavourable heat environments. It must also be noted that this material has a good resistance to cold and does not give off corrosive gases during combustion.

- Ethylene-propylene copolymers, for rigid cables and particularly for flexible cables. This material offers poor resistance to oils and little resistance to the spreading of flames, but does not emit toxic products during combustion. Also used for HV.

- Silicone rubber, which has excellent resistance to extreme temperatures (between -80°C and + 250°C) and to external agents, ***giving it remarkable aging properties.***

Type of insulation	Maximum operating temperature (°C)
Polyvinyl chloride (PVC)	Conductor: 70
Cross-linked polythene and ethylene – propylene (EPR)	Conductor: 90
Silicone rubber	Conductor: 90

Table 4: Maximum operating temperatures for the insulations

5.3.3.3. Protective sheaths

When selecting the materials for protective sheaths, you must take the following points into consideration:

- External constraints exerted on the cable
- Operating conditions, maximum temperature
- Installation conditions, minimum temperature
- Type of insulation used, particularly in terms of heat resistance.

The materials used are:

- Insulation materials, such as those used for the insulation (see above paragraph)
- Lead or lead alloys
- Lead sheaths have:
    - Perfect sealing
    - Excellent chemical inertness
    - Sensitivity to vibrations and repeated deformation

- Poor mechanical properties which require protection in the form of an armour or laying in conduits or in a cable tray

- Vulnerability to certain forms of electrochemical or electrolytic corrosion

5.3.3.4. The screen

The screen protects the low current circuits against disturbances produced by nearby cables.

Individual screen (EI)

Individual screen per pair or per triplet, generally consisting of a spirally wound polyester tape covering, the screen's continuity is provided by a tinned copper drain wire strand laid along the cable.

General screen (EG)

Screen applied over the whole of the assembled conductors, its construction is identical to the EI screen, however the drain can be provided by 2 or 3 copper wire strands, according to the cable diameter.

The choice of the type of screen depends on the used of the cable in general:

- **DC power supply** cable: no screen

- cable for **high level** analogue and digital signals (4-20 mA, 24V, 48V): a general screen (EG),

- cable for **low level analogue signals**, compensation cable: individual screen (EI) + general screen (EG)

- cables for **digital signals**: individual screen (EI) + general screen (EG).

5.3.3.5. Mechanical protection

Provided by an armour either consisting of:

- Two mild steel tapes, sometimes galvanised or PVC coated, spirally wound at the joints. Disadvantage: rigidity, sensitivity to corrosion

- One or two layers of spirally wound steel wires, generally galvanised. These wires can have a PVC sheath.

Advantage: improved flexibility, good resistance to longitudinal forces.

Disadvantage: high price.

5.3.4. Examples of instrumentation cables

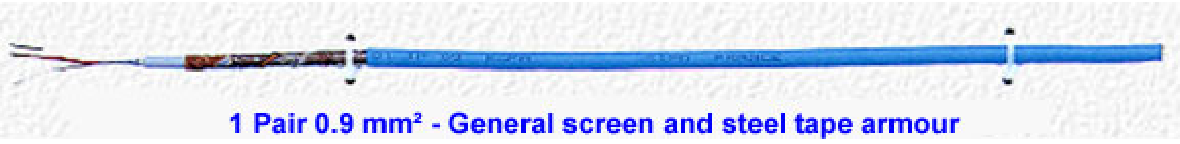


Figure 50: Instrumentation cable 01IP09EGFA

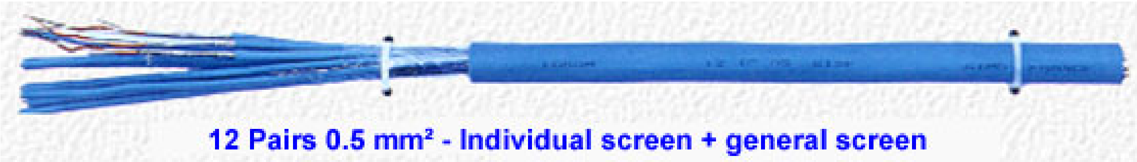


Figure 51: Instrumentation cable 12IP05EISF

Figure 52: Instrumentation cable 27IP05EIFA

5.3.5. Summary

The following table gives the types of instrumentation cables which you are going to encounter throughout your career as an instrument technician:

Designation	Number of pairs	Number of triplets	Number of quads	Armour
01 IP 09 EG FA	1	0	0	Metal tape
01 IP 09 EG SF	1	0	0	Nonarmoured
01 IQ 09 EG FA	0	0	1	Metal tape
01 IQ 09 EG SF	0	0	1	Nonarmoured
01 IT 09 EG FA	0	1	0	Metal tape
01 IT 09 EG SF	0	1	0	Nonarmoured
03 IP 05 EG SF	3	0	0	Nonarmoured
03 IP 05 EI SF	3	0	0	Nonarmoured
07 IP 05 EG SF	7	0	0	Nonarmoured
07 IP 05 EI SF	7	0	0	Nonarmoured
07 IT 05 EG SF	0	7	0	Nonarmoured
12 IP 05 EG SF	12	0	0	Nonarmoured
12 IP 05 EI SF	12	0	0	Nonarmoured
12 IT 05 EG FA	0	12	0	Metal tape
12 IT 05 EG SF	0	12	0	Nonarmoured
19 IP 05 EG FA	19	0	0	Metal tape
19 IP 05 EG SF	19	0	0	Nonarmoured
19 IP 05 EI SF	19	0	0	Nonarmoured
19 IT 05 EG SF	0	19	0	Nonarmoured
27 IP 05 EG SF	27	0	0	Nonarmoured

Table 5: Some types of instrumentation cables

As you can see, they are also available with multiconductors which range from 3 to 27 pairs and from 1 to 12 triplets. These multiconductor cables are called ***"multis"*** in maintenance jargon.

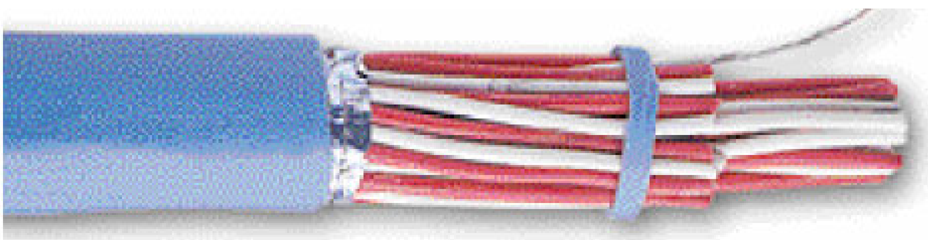


Figure 53: Multipair instrumentation cable

5.4. SPECIAL INSTRUMENTATION CABLES

5.4.1. Reminder of the thermocouple measuring principle

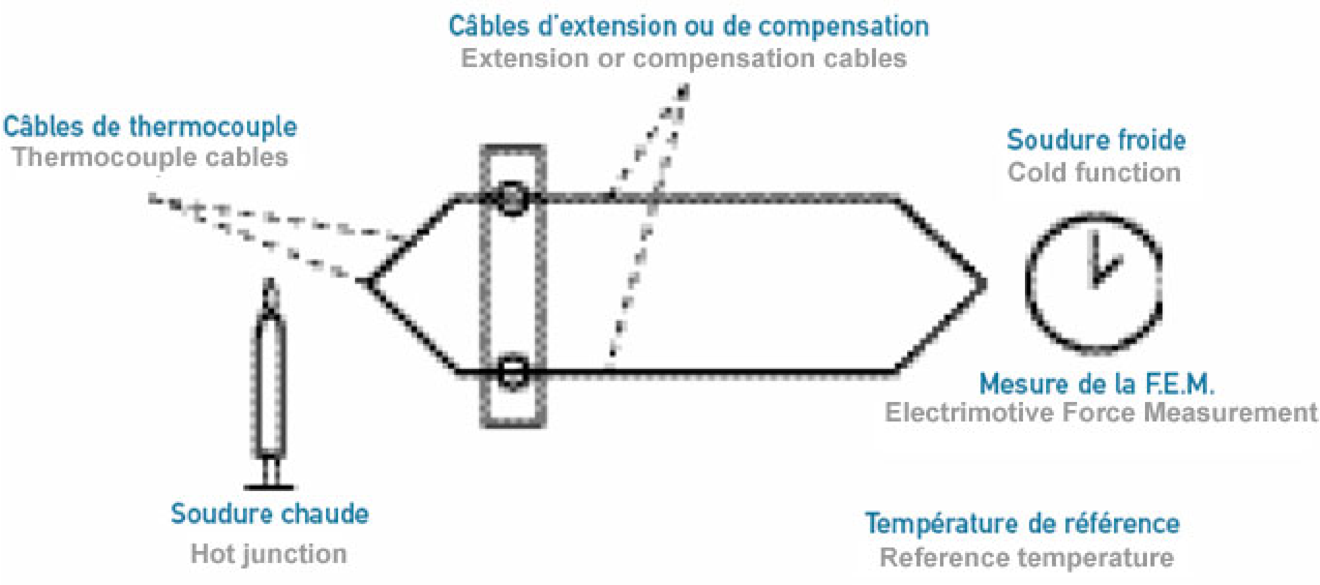


Figure 54: Thermocouple measuring principle

At the terminals of a circuit formed by two conductors (couples) of different type (e.g. iron-constantan) an electromotive force (emf) can be measured which is directly proportional to the temperature variation recorded in the hot zone.

The materials used depend on the temperature range to be measured. The couples are symbolised by the letters: " J-K-S ".

To be able to move the measurement zone (cold zone) away from the hot zone we use ***compensation cables***: they are less expensive than thermocouple cables (markings JC – KC – SC).

The ***extension cables*** provide the same function with a greater precision (lower tolerance).

They are more expensive than compensation cables (markings JX – KX – SX).

A colour code is used to identify the different cables according to each country's standards.

5.4.2. Thermocouple compensation cables

Extension cables are used to extend the thermocouple circuits, they take the form of an electric cable whose conductors are made of the same materials as those of the thermocouple.

Compensation cables are made of other materials (cheaper) whose thermoelectric characteristics are identical up to 100°C

The compensation cables are defined by the IEC 584-3 standard which, among other things, determines the cable colour code and the polarity

Figure 55: Various compensation cables

Practical information:

Couple type	Sheath colour
K	green
J	black
T	brown
S and R	orange

The positive conductor always has the same sheath colour. The negative conductor is always WHITE.

Important: any temperature inversion of a compensation cable generates spurious thermoelectric junctions which affect the measurement precision and stability (fluctuations linked with the variation in ambient temperature).

Material	Temp. Min.	Temp. Max.
PVC (HV)	- 50 °C	+ 80 °C (105 °C)
Polythene	- 60 °C	+ 70 °C
Polypropylene	- 40 °C	+ 105 °C
Nylon	- 70 °C	+ 120 °C
Polyurethane	- 40 °C	+ 80 °C
Teflon FEP	- 80 °C	+ 205 °C
Teflon PTFE	- 80 °C	+ 260 °C
Teflon PFA	- 80 °C	+ 260 °C
Tefzel	- 80 °C	+ 155 °C
Halar	- 60 °C	+ 160 °C
Silicone	- 55 °C	+ 230 °C
Kapton	- 75 °C	+ 260 °C
Fibre glass	- 70 °C	+ 650 °C
Ceramic fibre	0 °C	+ 1430 °C

Table 6: Temperature resistance of the insulations used on the extension or compensation cables

5.4.2.1. Compensation cable codings

Type		Couple	**U**
		Compensation	**M**
		Connection	**L**
Thermocouple standard		IEC	**C**
Number of conductors			**2**
			3
			4
			5
			Etc.
Type		Tc K	**K**
		Tc J	**J**
		Tc S	**S**
		Tc T	**T**
		Tc B	**B**
		Copper	**U**
Conductor insulation		Kapton	**K**
		Fibreglass silk	**V**
		PFA	**Fa**
		FEP	**Fe**
		PTFE (teflon)	**Tf**
		Silicone	**S**
		PVC	**P**
Internal screen		Screened	**B**
Sheath insulation		Kapton	**K**
		Fibreglass silk	**V**
		PFA	**Fa**
		FEP	**Fe**
		PTFE (Teflon)	**Tf**
		Silicone	**S**
		PVC	**P**
External screen		Screened	**B**
Wire	Cross-sectional area (mm²) (Compensation and connection)		**0.14**
			0.22
			0.50
			0.80
			1.00
			1.34
			Etc.
	Diameter (mm) (Couple)		**0.3**
			0.5
			Etc.

Table 7: Cable codings

5.4.2.2. Colour codings

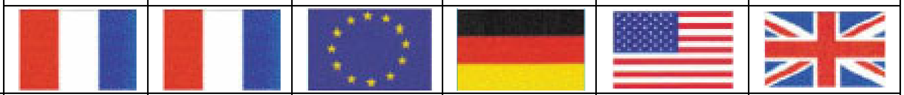
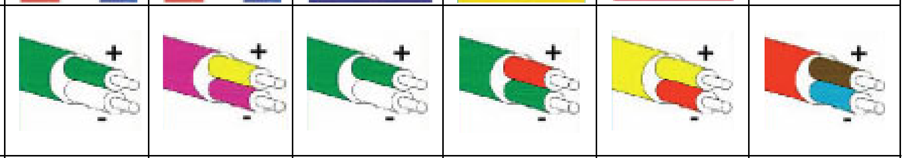
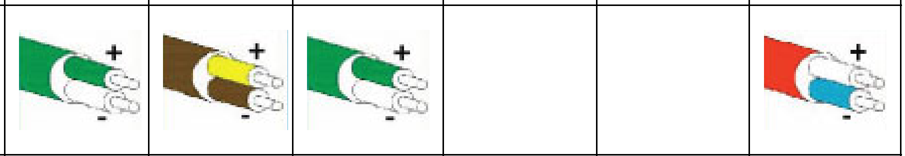
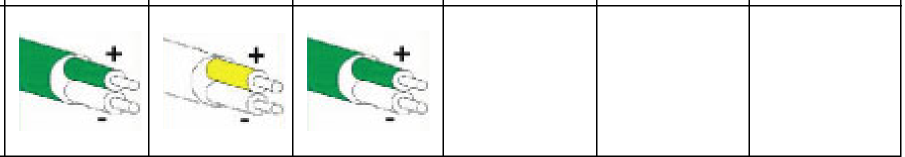
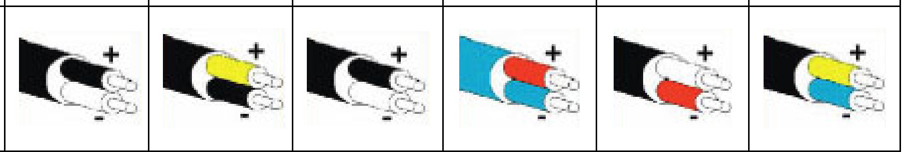
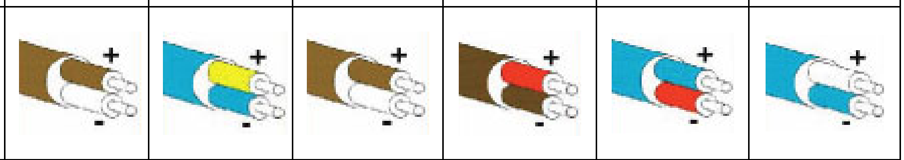
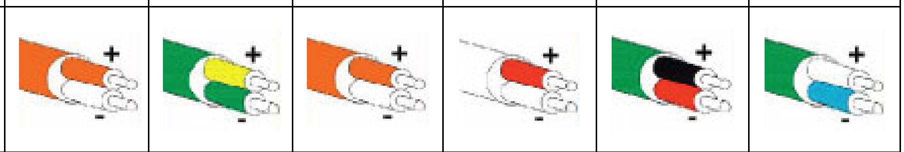
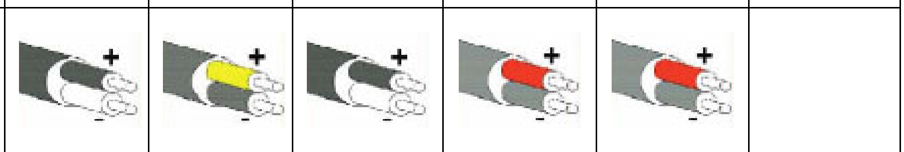
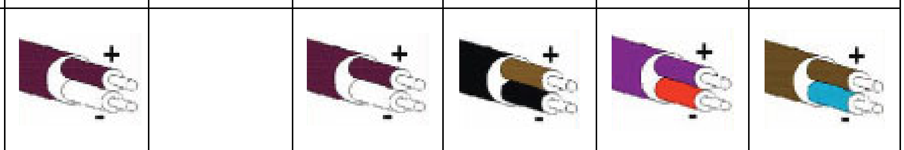
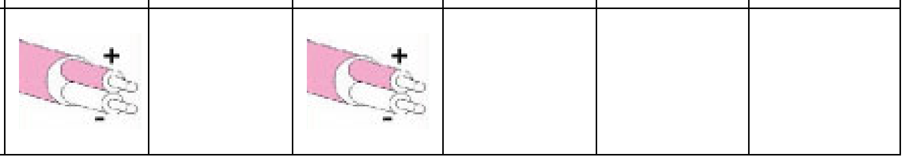
	Conductors		Symbols	French standard NFC 42324 DE 1993	Old French standard NFC 42324	European standard IEC 584.3	German standard DIN 43714	US standard ANSI MC 96.1	UK standard BS 1843
Symb	Positive	Negative							
K	Chromel	Alumel	K X						
K	Copper	Constantan	K C B						
K	Iron	Cupronickel	K C A						
J	Iron	Constantan	J X						
T	Copper	Constantan	T X						
S or R	Copper	Cupronickel	S C B						
B	Cupronickel	Copper	B C						
E	Chromel	Constantan	E X						
N	Nictosil	Nisil	N X						

Table 8: Compensation cable colour coding

5.4.3. Network cables

5.4.3.1. Profibus cable

Figure 56: PROFIBUS cable

The Profibus-DP protocol uses a high speed RS485 serial link and imposes an impedance of 150 ohms.

Electrical characteristics:

Service voltage: 100 V

Test voltage 2,000 V

Impedance: 150 Ω+/- 10%

Capacitance: 30 pF/m

Electrical resistance: 50 Ω/km

Loop resistance: 100 Ω/km

5.4.3.2. Ethernet cable

Ethernet cable is now very often used because of the developments in PLCs and PLC control systems which are based around industrial computer networks.

It uses two pairs of twisted wires, one pair is used to receive data signals and the other is used to transmit data signals.

The two wires in each pair must be twisted together along the whole length of the segment, this technique is often used to improve signal quality.

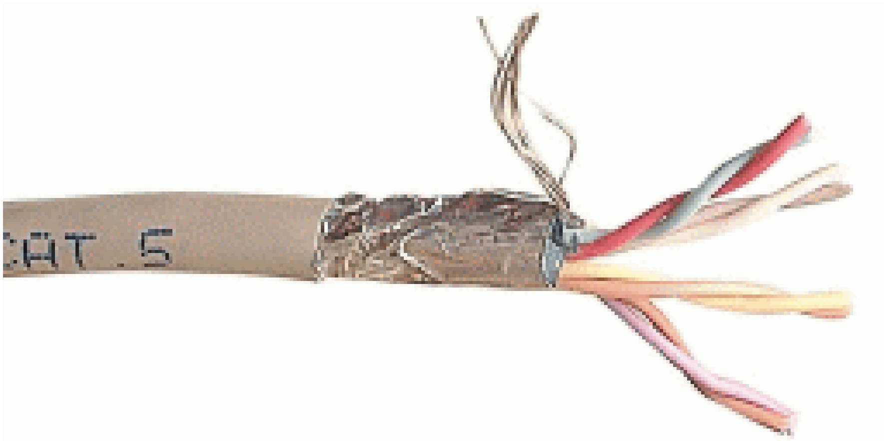
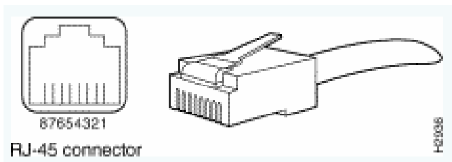


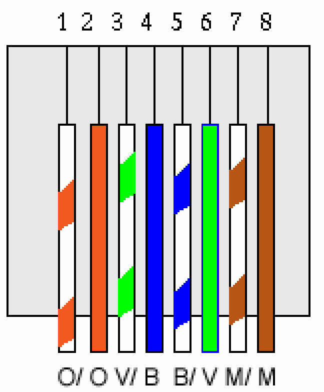
Figure 57: Ethernet cable

RJ45 connector

This connector is derived from that used for the telephone (RJ11) but it is physically incompatible with it (it is wider) and can contain more wires (8 compared to 6, whereas the conventional RJ11 uses only 4 wires).

The standard pin configuration is shown here (following figure) with the standard colours. It must be noted that the odd pins are always those with striped colours.





With the connector's clip located underneath

Colour codings

Pin	Colour	Pair	Name
1	Orange / White	2	TxData +
2	Orange	2	TxData -
3	Green / White	3	RecvData +
4	Blue	1	
5	Blue / White	1	
6	Green	3	RecData -
7	Brown / White	4	
8	Brown	4	

Figure 58: The RJ45 connector and its colour code

Straight RJ45 cable

It is the most widely used model, it is always used when connecting an Ethernet interface to a hub or to a switch. The pin assignments are identical at each end of the cable:

Table 9: Straight RJ45 cable

Signal	Pin	Pin	Signal
TxData+	1	1	TxData+
TxData-	2	2	TxData-
RecvData +	3	3	RecvData +
-	4	4	-
-	5	5	-
RecvData-	6	6	RecvData-
-	7	7	-
-	8	8	-

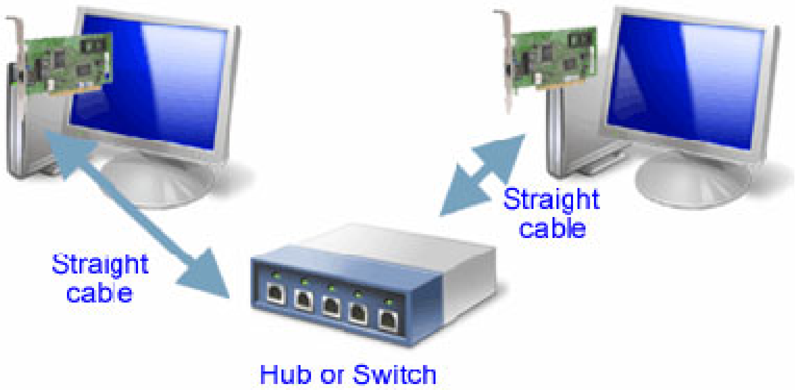


Figure 59: Example of an application with a straight RJ45 cable

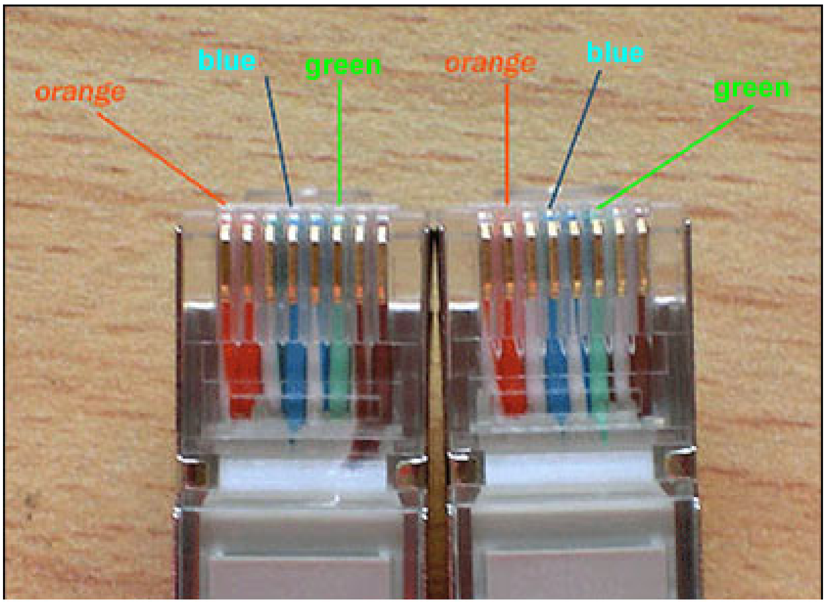


Figure 60: Straight cable

RJ45 crossover cable

Used to directly connect two Ethernet interfaces together. The pin configuration at one end is different to allow communication to take place: the transmission and reception wires are reversed.

Signal	Pin	Pin	Signal
TxData+	1	1	RecvData+
TxData-	2	2	RecvData-
RecvData+	3	3	TxData+
-	4	4	
-	5	5	
RecvData-	6	6	TxData-
-	7	7	
-	8	8	

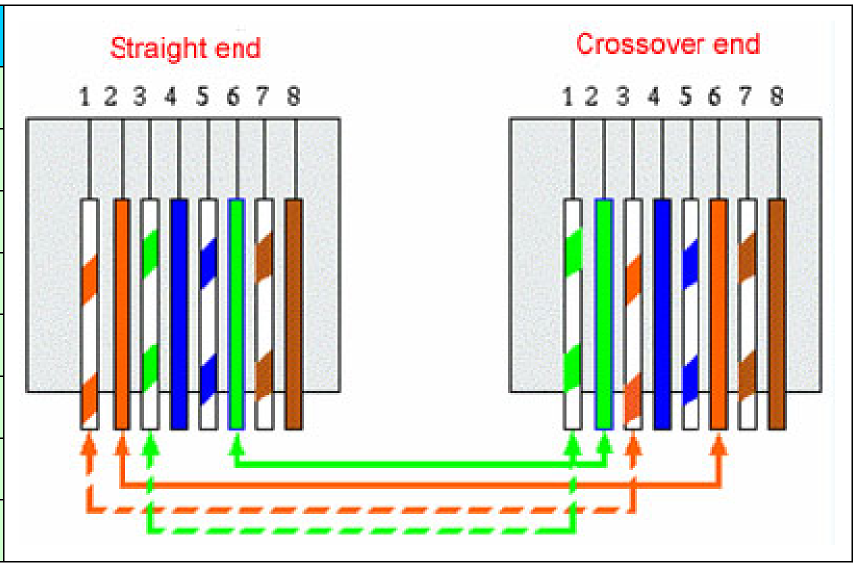


Figure 61: Ethernet cable with RJ45 crossover connector

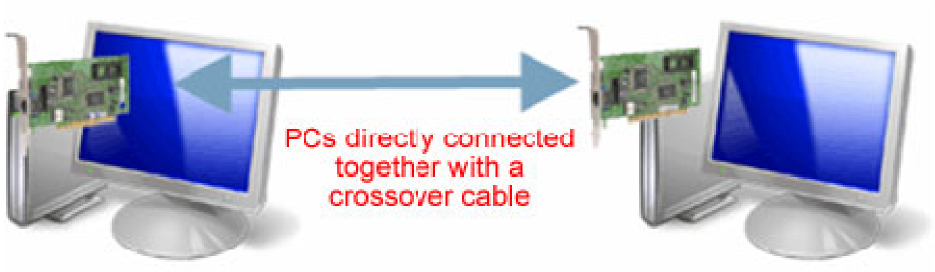


Figure 62: Example of an application with an RJ45 crossover cable

As you can see in this example, using a crossover cable we can directly connect two computers in an Ethernet network.

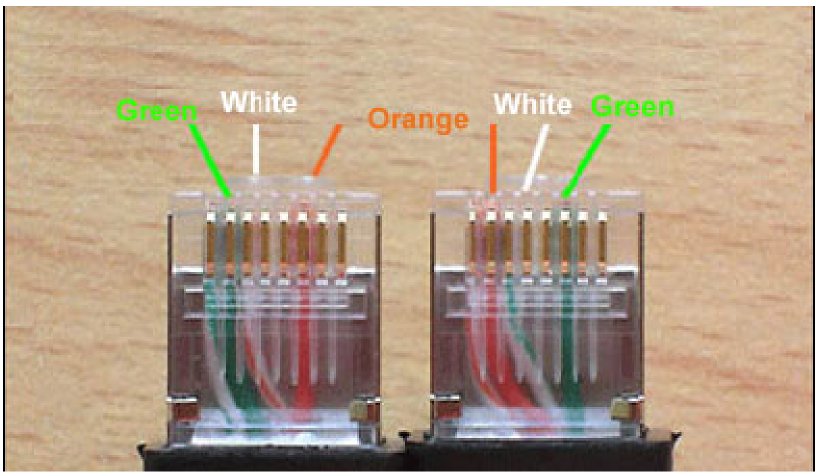


Figure 63: Crossover cable

5.4.3.3. Determining the type of RJ45 cable

Take the two ends as shown in the following diagram and look closely at the order of the wires:

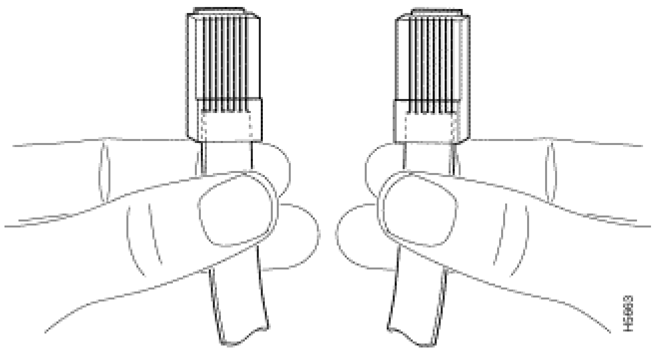


Figure 64: Determining the type of RJ45 cable

IMPORTANT: *The colour codes indicated in the previous tables correspond to a standard but it is quite possible to find cables which use wires with completely different colours.*

- if the colour sequence is identical at each end: **straight cable**
- If pins 1-2 and 3-6 are reversed: **crossover cable**
- Neither one or the other: "unknown" cable, or at least a cable which does not respect an Ethernet configuration.

5.4.3.4. RJ45 cable categories

Each RJ45 cable is attributed a category which defines the maximum amount of data (data speed) speed which it can transfer without errors.

Normally, each RJ45 cable you find on the market is marked along its length with a set of data and the cable category.

The following table gives the different categories with their current usage:

Category	Maximum data speed	Normal application
CAT 1	Less than 1 Mbps	Voice in analogue mode (telephone) Nominal data speed of Integrated Service Digital Networks (ISDN) Doorbell wiring
CAT 2	4 Mbps	Mainly used for IBM token ring
CAT 3	16 Mbps	Voice and data transport for Ethernet 10baseT
CAT 4	20 Mbps	Used for the high speed version of the token ring (16 Mbps), otherwise it is not very commonly used

Category	Maximum data speed	Normal application
CAT 5	100 Mbps 1000 Mbps (4 pairs)	100 Mbps (twisted pair): 100baseTX 155 Mbps ATM Gigabit Ethernet
CAT 5E	100 Mbps	100 Mbps (twisted pair): 100baseTX 155 Mbps ATM
CAT 6	200-250 Mbps	Very high data speed applications

Table 10: RJ45 cable categories

5.4.3.5. Making your RJ45 cable

The first thing you need is some category 5 cable. This can be obtained from computer or electronics retailers, etc. You can also choose to shorten the cable supplied with the machine.

Figure 65: Category 5 cable

The crimping tool for RJ45 connectors is more expensive. This one is relatively cheap (around 15 euros). Near its hinge it has two blades which strip the cable, as well as a crimping part and a cutting part.

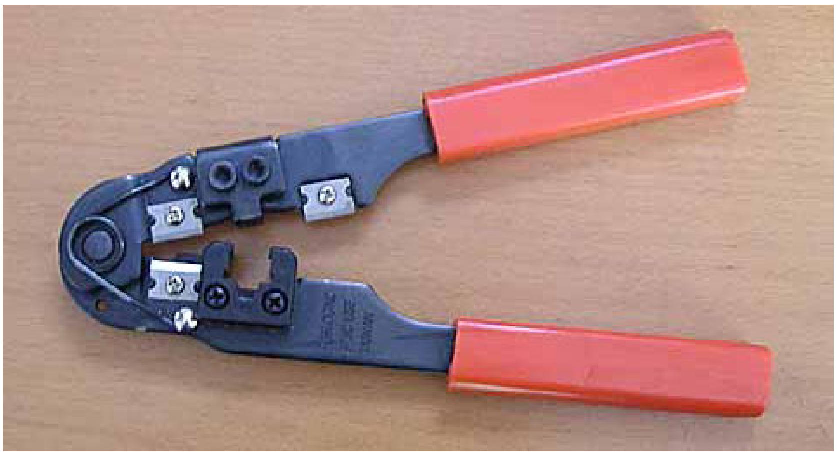


Figure 66: Crimping tool for RJ45 connectors (1)

I prefer to use this one, it only crimps but it does a very good job!

Figure 67: Crimping tool for RJ45 connectors (2)

You also need the RJ45 connectors and any coloured caps which may be necessary. The caps are used to identify the different cables and protect the Ethernet connector's clip. You obviously have to insert the cap before crimping the connector.

I would not use one on this cable because it is designed to remain in place and, because of its length, we can immediately see what it is connected to.

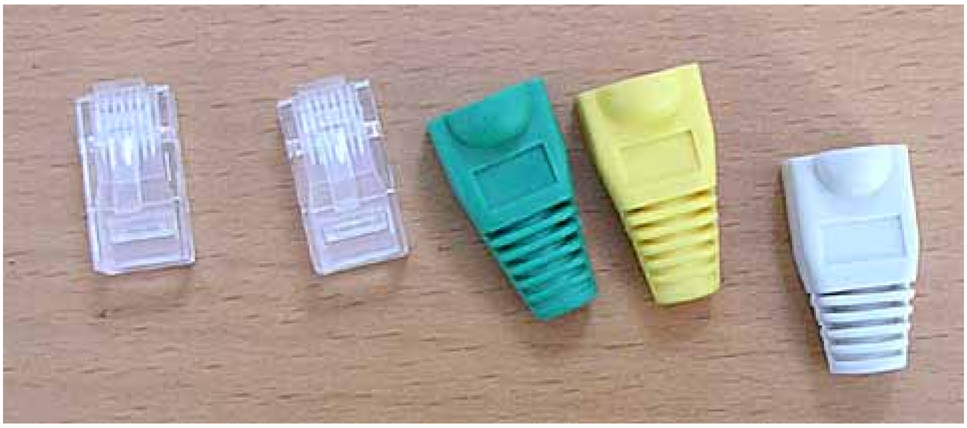


Figure 68: RJ45 connectors (1)

The connectors can be different, with guides, without guides, screened. In this case these are simple connectors.

On this side we can see the metal pins which will later fit onto the cable's wires.

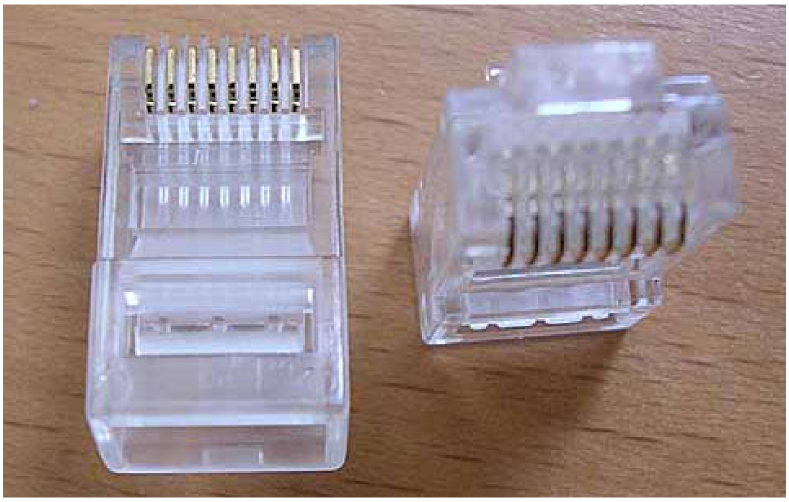
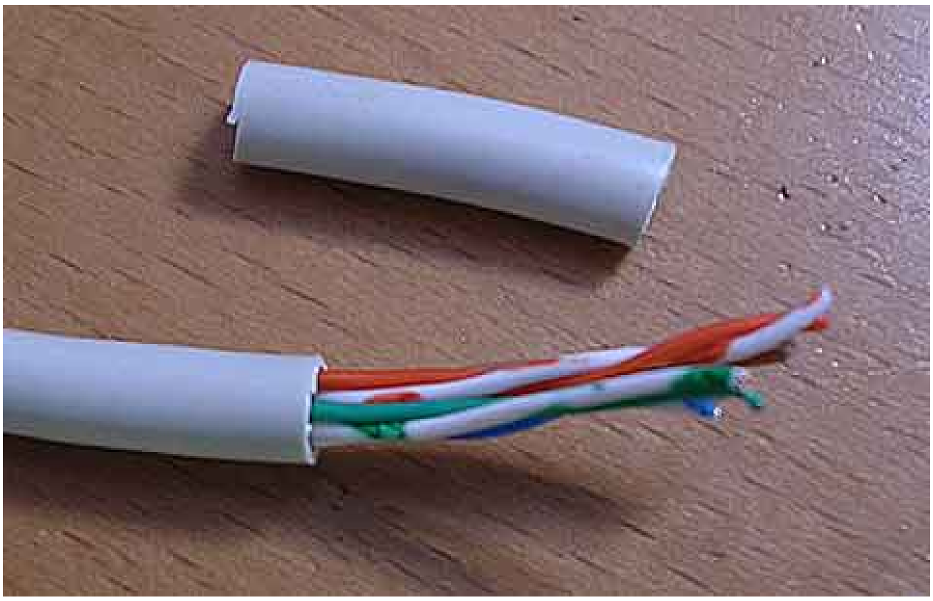


Figure 69: RJ45 connectors (2)

Personally, I don't use the stripping part of the various tools, I prefer to use a utility knife, and make a cut between 2 and 3 cm from the end of the cable

Figure 70: Using a utility knife

.



In this way, I know that the conductors will not be damaged and I have enough length to untwist the pairs and lay them flat.

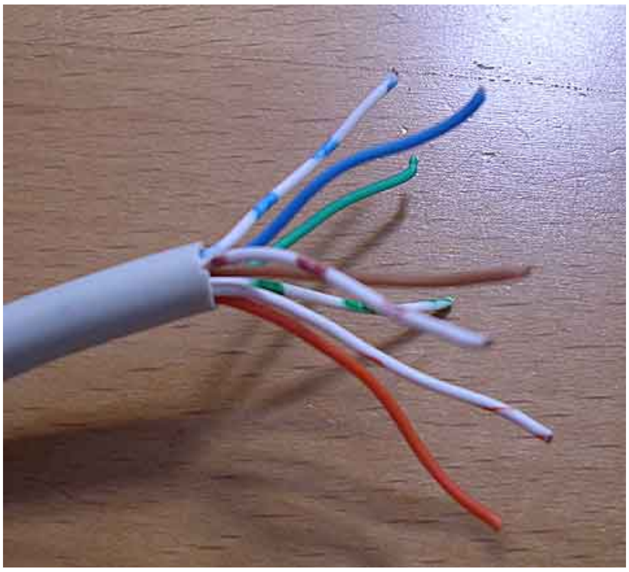
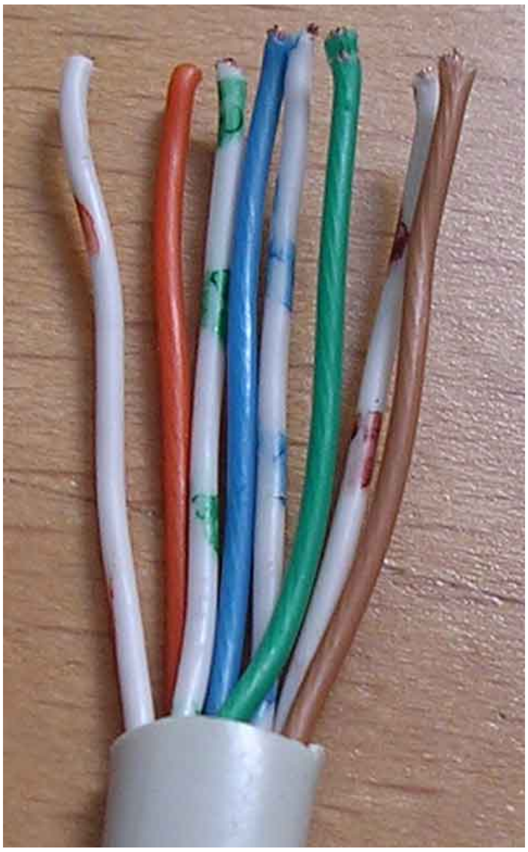


Figure 71: Untwisted cable



And the conductors are laid out flat in the correct order:

- white/orange
- orange
- white/green
- blue
- white/blue
- green
- white/brown
- brown

Figure 72: Untwisted cable with colours in the correct order

For a straight cable, the two ends must be placed in this manner.

For a crossover cable, one end must be as indicated above and the other must be as specified below:

- white/green
- green
- white/orange
- blue
- white/blue
- orange
- white/brown
- brown

The two pairs currently used (base 10 and base 100) are those which will be crossed over (or left straight).

After cutting the conductors straight, we slide them fully into the connector, as shown here.

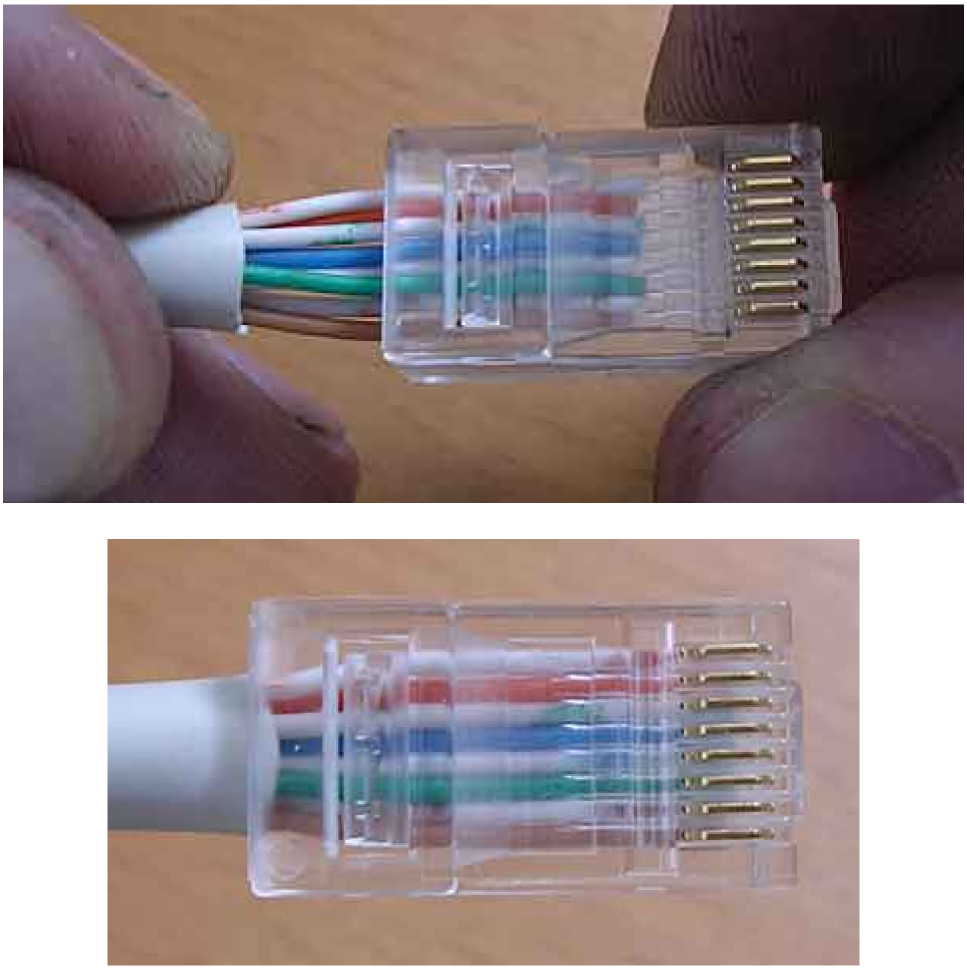


Figure 73: Slide the cable into the connector

Then push the sheath as far as possible.

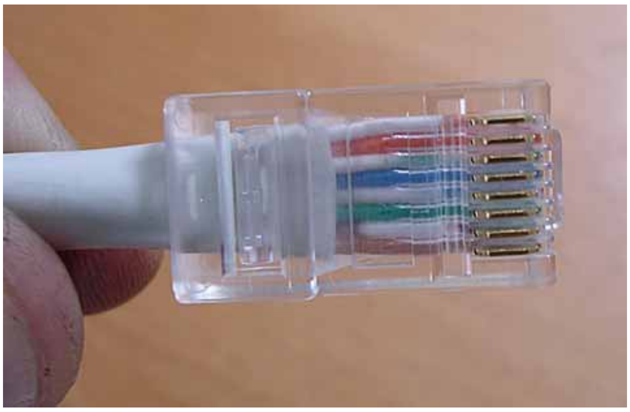


Figure 74: Push the sheath

We can see that the cables are fully inserted.

Figure 75: Cable fully home in the connector

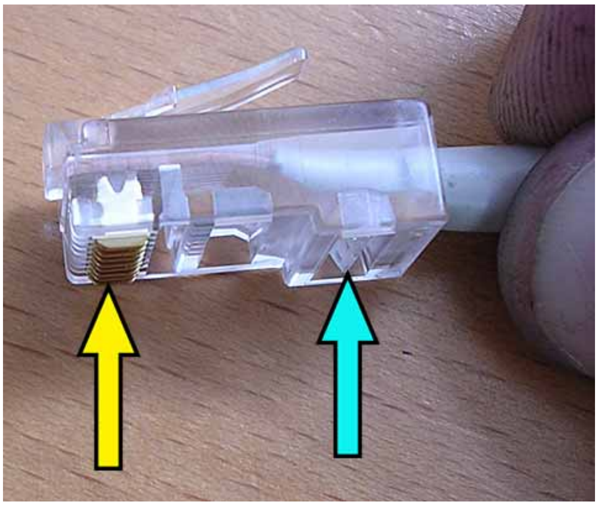


Figure 76: Position of the contacts and of the plastic locking device

The yellow arrow indicates the contacts which will be inserted onto the conductors, the blue arrow indicates the plastic locking device which will secure them and their sheath in the connector.

We insert the connector carefully but firmly into the crimping tool.

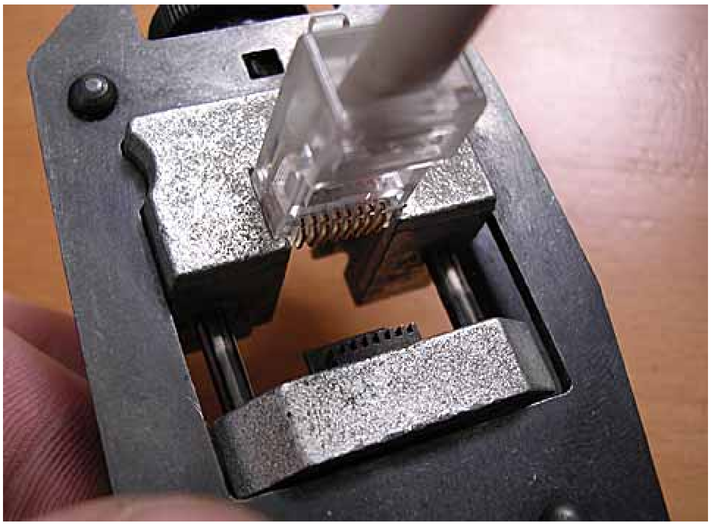
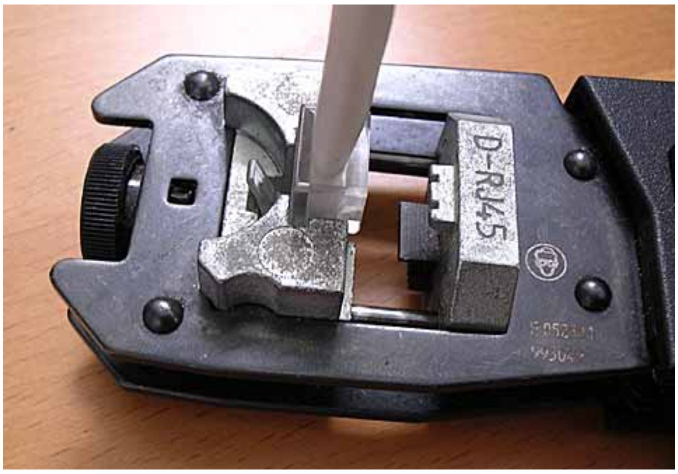


Figure 77: Inserting the connector into the crimping tool



When the connector has been clipped into the tool, check that the cable and sheath are fully inserted before crimping. When it has been crimped, repeat the operation for the other end of the cable.

Figure 78: Connector clipped in the crimping tool

And our cable is now ready to use. In this example we made a 10 cm long cable but you can make the cable any length you wish.

Figure 79: Ethernet cable

5.4.3.6. Reminder on HUBS and SWITCHES

General description:

All the data flowing in the network transits via these units. They have from 4 to 48 RJ45 ports and can thus interconnect as many Ethernet interfaces. They can also be interconnected together via an uplink port.

This uplink port is always shared with one of the conventional RJ45 ports, which means that you lose one port when you connect two hubs/switches together. Thus, connecting two 8-port hubs together will result in a total of 14 ports available instead of 16.
There are two types of hubs/switches:

- **conventional hubs/switches** (desktop/palmtop): the most commonly used models, they are also the cheapest, and they are designed to be placed on a desk and therefore have an attractive design. They have from 4 to 16 ports and, depending on the model, the power supply may be internal or external.

- **rackable hubs/switches**: they are the largest and most expensive models, they are designed to be installed in rack units (more commonly known as cabinets). They have from 8 to 48 ports and have an internal power supply. The recent models are beginning to integrate gigabit Ethernet ports (1000baseTX or 1000baseFX). The top-of-the-range models very often have a remote monitoring software suite. It must also be noted that there are stackable models available. Their specific feature is that they can be interconnected together (up to 8 devices depending on the models) via special boards thus allowing very high speed transfers between all the switches without the risk of creating bottlenecks.

Hub operating principle

A hub retrieves the signals from a port and sends them to all the other ports. This means that each data packet from an Ethernet interface connected to the hub is sent to all the other interfaces present on this hub. Thus we are sure that the intended receiver of the packet actually receives it.

The problem is that the packet is also received by all the interfaces which it is not destined for. This generates a lot of unnecessary traffic on the network and the network becomes more and more saturated as more and more Ethernet interfaces are added to it. Since a hub has no means of managing the traffic it receives, the packets very often bump into each other (collision principle).

These collisions fragment the packets and so they have to be sent again, increasing the transfer times and therefore greatly reducing the effective speed of the network.

Switch operating principle

Whereas hubs only transfer packets over the network, switches are capable of managing the packets they receive in different ways. Their main feature is that they can consult the MAC address of the sender and of the receiver in each packet.

The MAC address is the unique ID number of each Ethernet interface. By keeping a trace of these MAC addresses, a switch knows which port each Ethernet interface is located on.

Practical example

A packet arrives on port 2 with X as destination address and Y as source address. The switch immediately knows that address Y corresponds to port 2 since the packet arrived via this port. At the same time, a packet arrives by port 5 with Z as destination address and X as source address. The switch now knows that address X is on port 5 and thus knows the destination of the first packet from port 2 (with MAC address Y).

In theory this series of events happens only once for each MAC address because each switch has an address table containing this data for future reference.

In addition to reducing the unnecessary traffic on each port, recent switches are capable of reducing the number of collisions even further by using CSMA/CD (Carrier Sensing Multiple Access/Collision Detection).

This feature is used among other things to check the state of the line before sending data. If it detects that there is traffic on the line, it waits till the line is free before making the transfer.

CSMA/CD also allows the switch to query each packet it receives and to reject those which are fragmented or damaged, thus reducing the unnecessary traffic even more.

Finally, a last technical point: most switches are of the "store-and-forward" type. This means that a switch retrieves a complete packet before sending it to its destination.

The switch can therefore analyse the packet (e.g. to find out if it is a fragment resulting from a collision) and decide if it must send it or reject it.

Store-and-forward switches must be differentiated from the cross-point models: cross-point models start to send the packet before they have completely received it.

This gives a shorter latency time but these models are much more expensive and the store-and-forward technologies have reached such a level of efficiency that cross-point switches are extremely rare. All the switches available on the market are store-and-forward switches.

6. CONNECTING INSTRUMENTATION CABLES

6.1. CABLE GLANDS

6.1.1. Introduction

In electricity and in instrumentation a cable gland is a component which allows an electric cable to pass through a partition, wall or bulkhead.

It provides a **seal** against foreign matter, dust, water, etc., and mechanically locks the cable.

It can consist of several elements, e.g.:

- A main part with dual thread forming a sleeve for the cable;
- A nut which fixes the body of the cable gland to the partition, associated if necessary with a seal,
- A pressure-deformable sleeve: formerly made of tow but now made of rubber or synthetic material and which provides the sealing;
- A nut which, either by deforming the end of the cable gland body, or using a cylindrical or tapered wedge, applies pressure to the deformable sleeve.

The cable passes through all the parts, in other words the cable gland is assembled by sliding the different elements onto the cable.

A cable gland can be made of metal (usually brass), or synthetic material (plastic).

Figure 80: Example of a standard plastic cable gland

A metal cable gland can, where necessary, be used to earth the cable screen (triple effect cable gland).

Figure 81: Standard metal cable gland

It is important to use the right type of cable gland according to the protection zones defined by the ATEX 95 standard.

The standard size of an instrumentation cable gland is **<u>M20 x 1.5</u>**.

It is important to ensure that the diameter of your cable gland correctly corresponds to your cable diameter because, on site, I once saw a large cable gland with a small cable and the whole assembly had been sprayed with silicone.

6.1.2. Procedure for electrically connecting a transmitter

Follow the instructions given below for wiring the transmitter:

1. Remove the plastic protection blanks, from one or both the electrical connections present on the sides of the top part of the transmitter housing.

2. Remove the cover from the housing on the connection side. For explosion-proof installations (certified Eex d), do not open the transmitter covers when the transmitter power supply voltage is present.

3. If an output indicator is present, remove it by unclipping it. Apply a strong pressure to the whole of the indicator to prevent the cover from coming away from its base.

4. Slide the cable into the cable gland and into the open access.

5. Connect the positive conductor to the + terminal and the negative conductor to the - terminal.

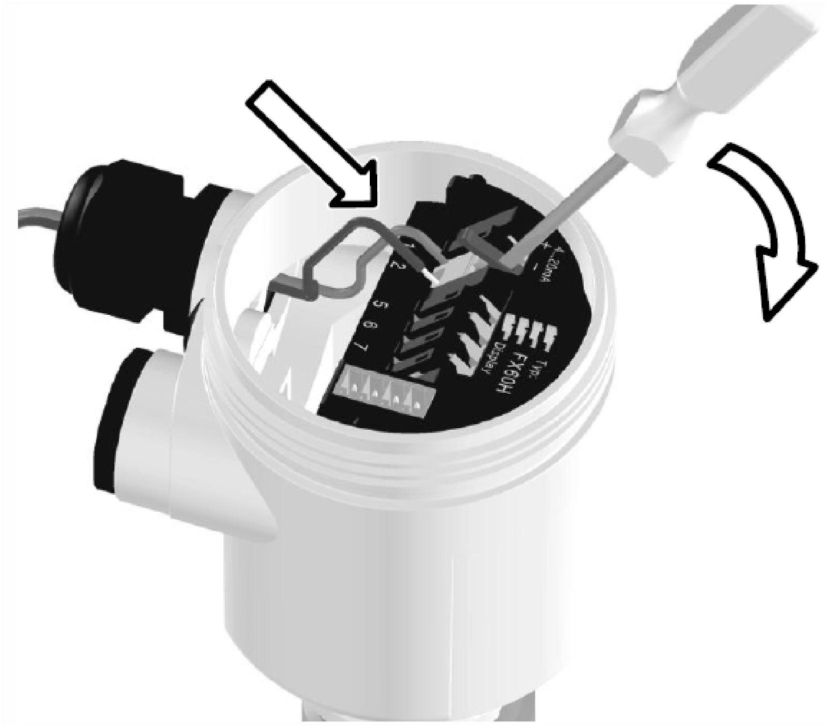


Figure 82: Electrically connecting the transmitter

6. Tighten the cable gland and seal the electrical accesses. When the installation procedure is terminated, ensure that the electrical accesses are correctly sealed against the ingress of rain, gas or corrosive vapours.

7. If possible, install the wiring with a '***drip loop***', where the bottom of the loop is below the conduit connection and the transmitter housing.

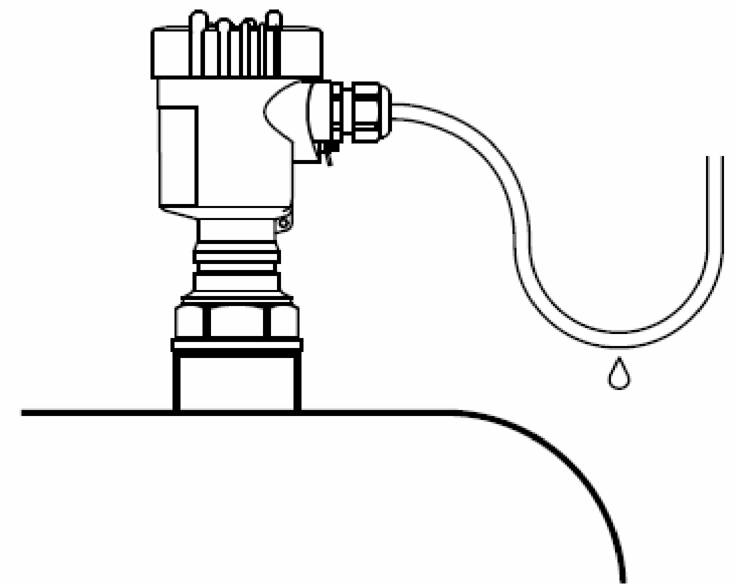
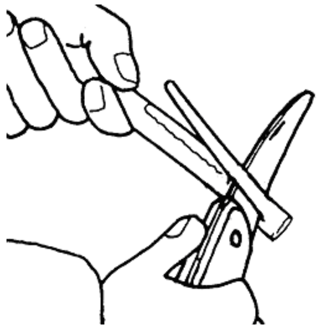
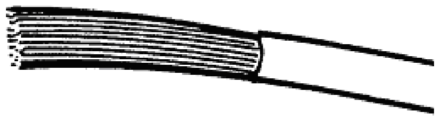
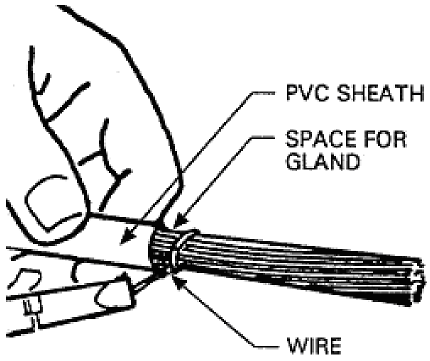
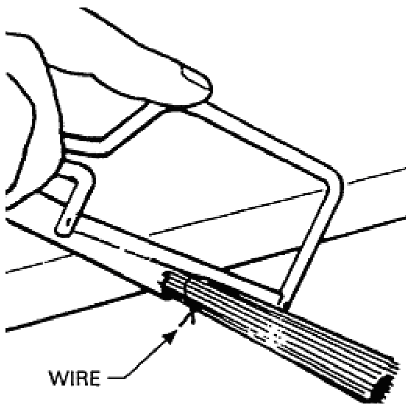


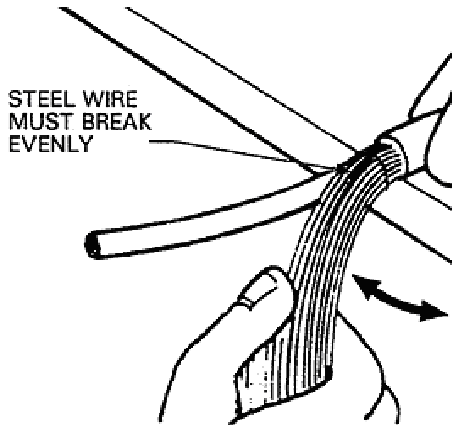
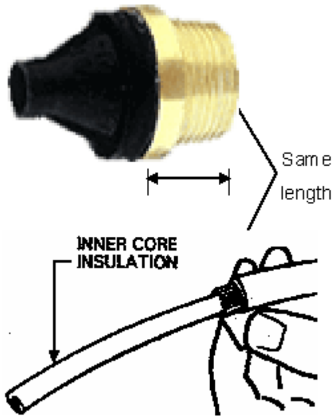
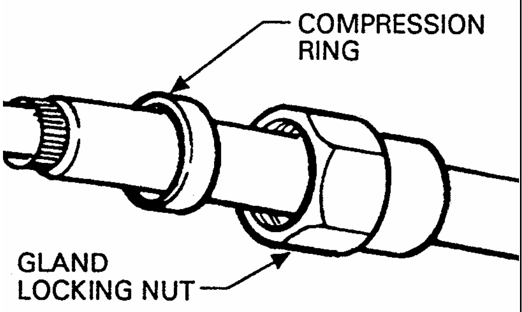
Figure 83: Drip loop on a transmitter

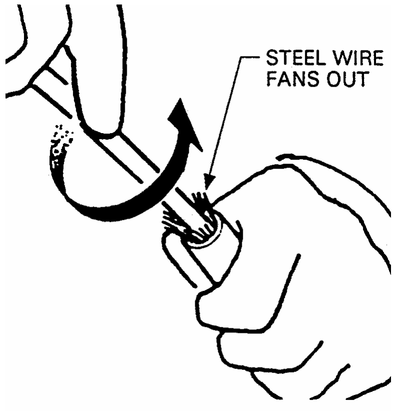
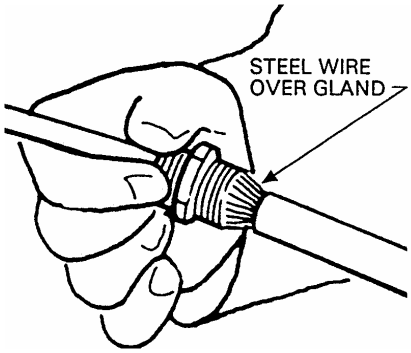
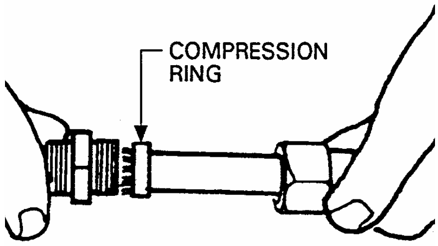
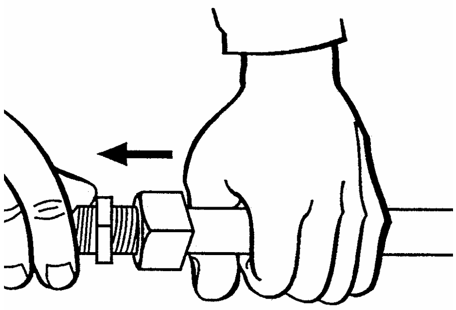
8. Screw up the housing cover by turning it until there is metal to metal contact between the cover and the transmitter housing. For explosion-proof installations EEx d or i, lock the cover by turning the locking screw.

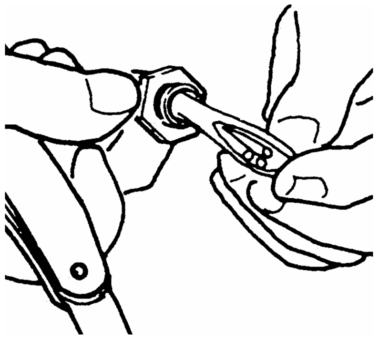
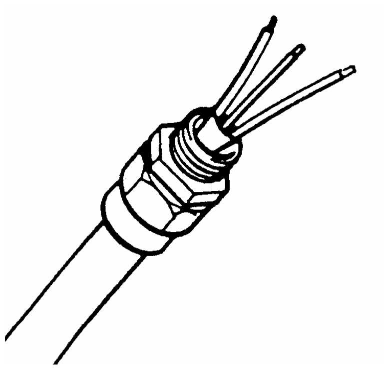
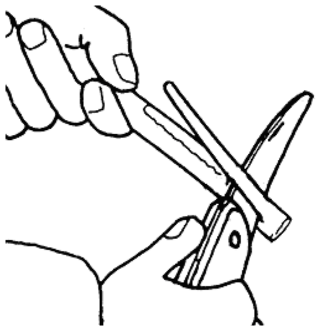
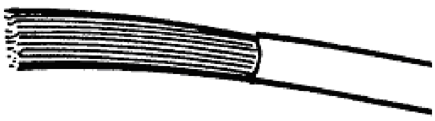
9. And that is all!! Your transmitter is now wired according to good instrumentation practices.

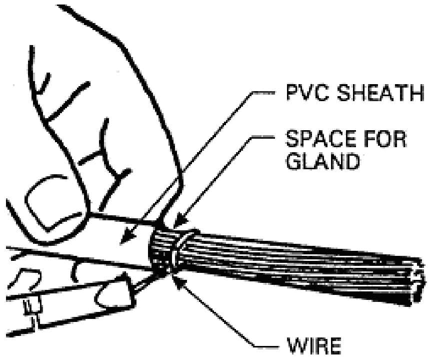
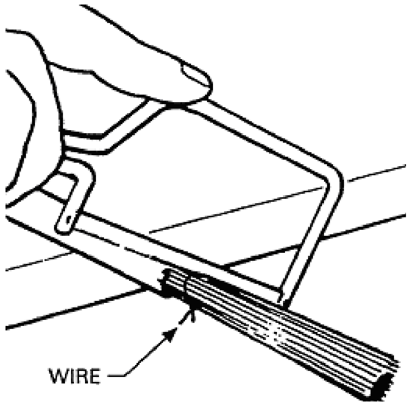
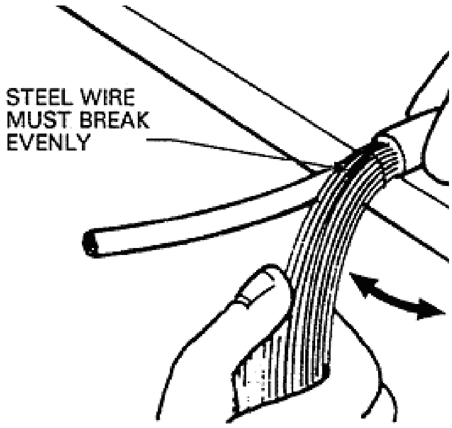
6.2. CONNECTING A CABLE TO A COMPRESSION COUPLING

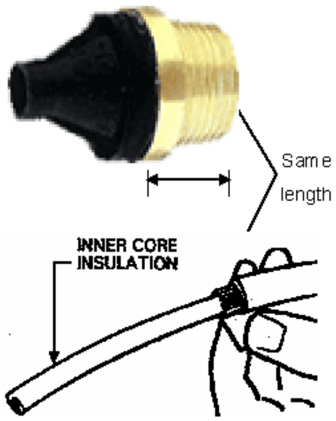
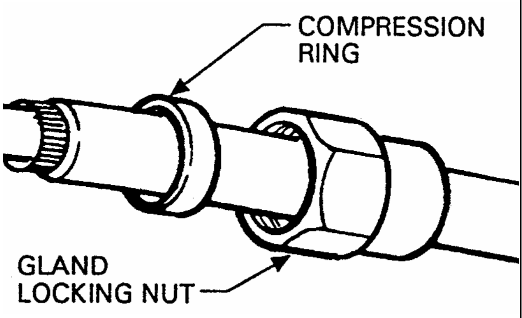
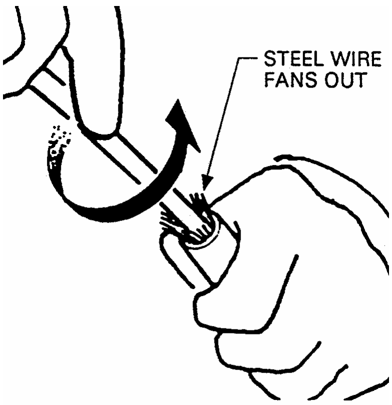
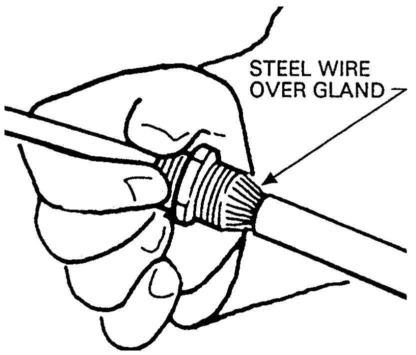
Mark the place where the cable armour must be cut.	
Cut away the PVC sheath with a knife.	
Expose (uncover) the armour.	
Tie a piece of wire around the armour. Leave a space for the cable gland between the wire and the end of the PVC sheath.	
Cut part of the way through the armour wire with a hacksaw. If you cut all the way through the armour you may damage the inner core insulation.	

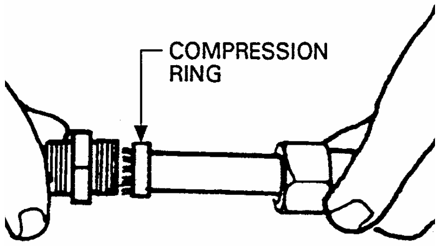
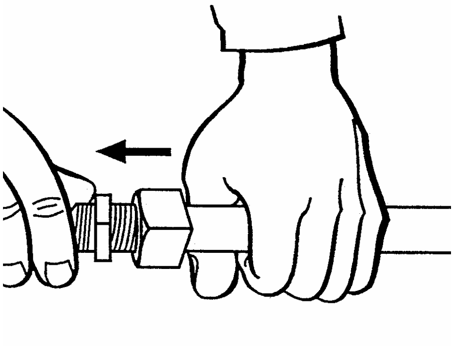
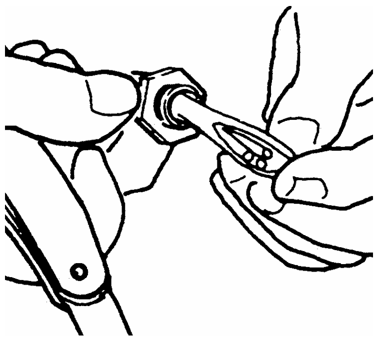
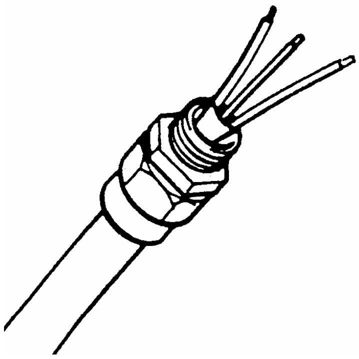
Cut the armour wires with a hacksaw. The wires must be cut evenly. Take only four (4) or five (5) strands at any one time.	
Cut back a little more of the outer sheath so enough of the armour is showing to cover the end of the clamping cone. Now you can see the insulation around the inner core.	
Place the gland locking nut and the compression ring over the cable.	

Twist the inner core against the lay of the steel wire armour. (depends on which end of the cable you are removing). The steel wire will fan out.	
Place the main body of the cable gland over the inner core. Make sure the steel wire goes over the top of the gland.	
Move the compression ring over the steel wire. Make sure the wire is gripped between the compression ring and the gland.	
Move the locking nut over the compression ring and tighten it on to the gland.	

Remove the inner PVC sheath to expose the conductors.	
Remove the insulation from the end of each conductor so the conductors can be terminated.	
Mark the place where the cable armour must be cut	
Cut away the PVC sheath with a knife.	
Expose (uncover) the armour.	

Tie a piece of wire around the armour. Leave a space for the gland between the wire and the end of the PVC sheath.	
Cut part way through the armour wire with a hacksaw. If you cut all the way through the armour you may damage the inner core insulation.	
Break off armour wires. The wires must break off evenly. Take only four (4) or five (5) strands at any one time.	

Cut back a little more of the outer sheath so enough of the armour is showing to cover the end of the clamping cone. Now you can see the insulation around the inner core	
Place the gland locking nut and the compression ring over the cable	
Twist the inner core against the lay of the steel wire armour. (Depends on which end off the cable you are making off). The steel wire will fan out.	
Place the main body of the gland over the inner core. Make sure the steel wire goes over the top of the gland.	

Move the compression ring over the steel wire. Make sure the wire is gripped between the compression ring and the gland.	
Move the locking nut over the compression ring and tighten it on to the gland.	
Remove the inner PVC sheath to expose the conductors	
Remove the insulation from the end of each conductor so the conductors can be terminated	

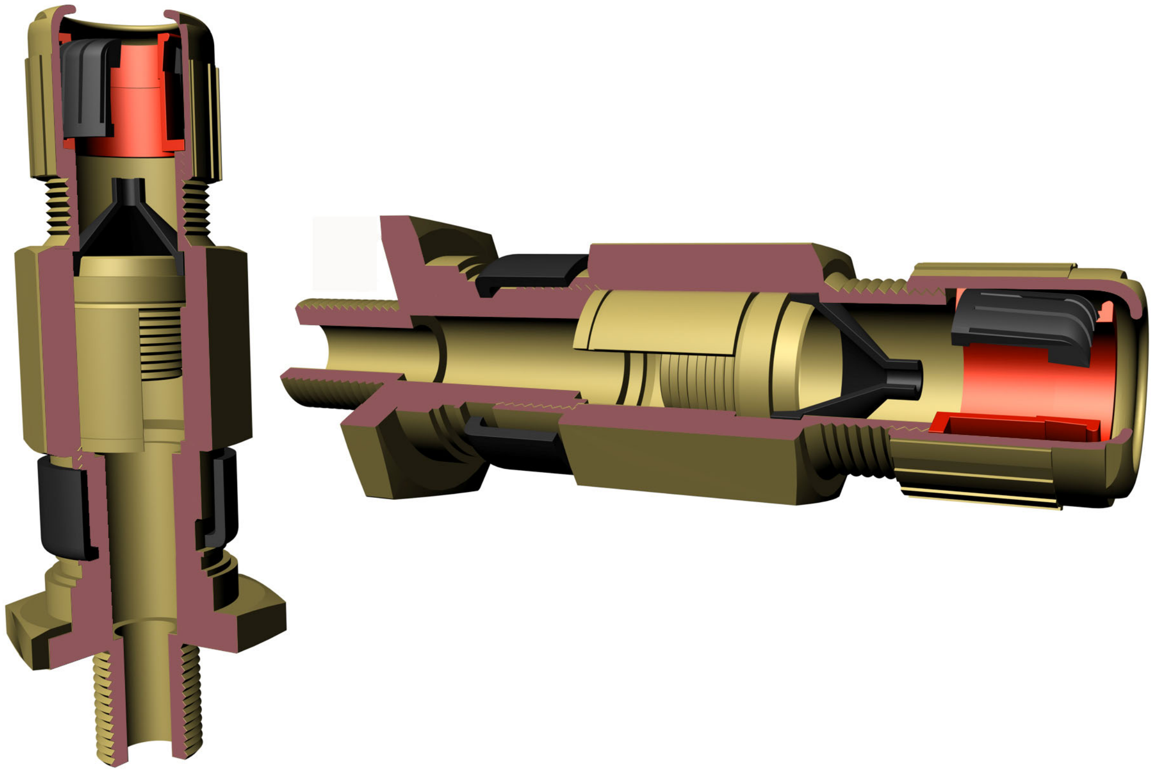


Figure 84: Cable gland with compression coupling

7. CABLE BRACKET - CABLE TRAY

7.1. GENERAL

You must start by differentiating the cable trays, each level of voltage has an assigned cable tray, each electrical field (and related fields) has a specific cable tray or a specific portion of cable tray.

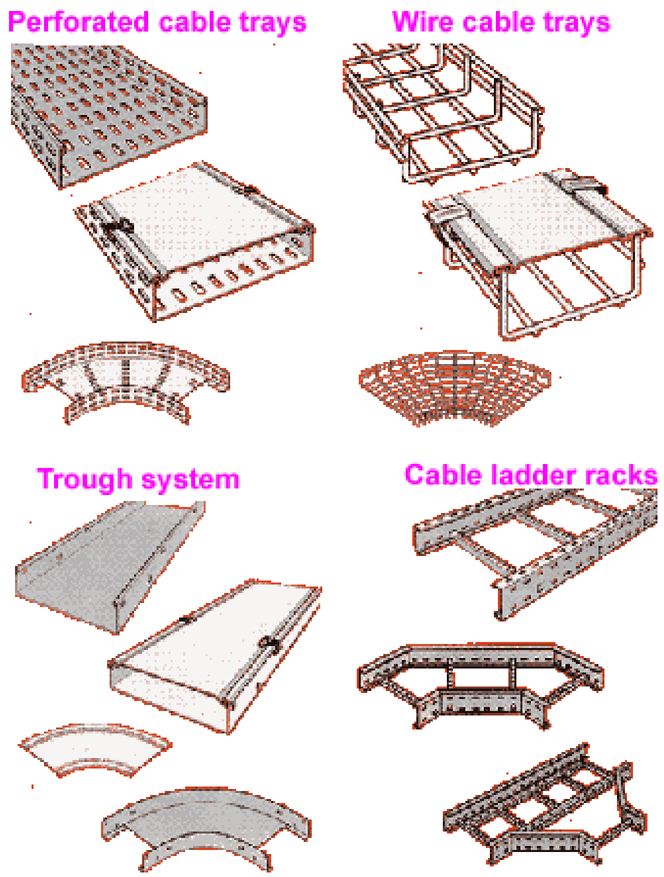
Each specific use or discipline has its own specific cables for technical reasons (interference, safety, etc.). There must be independent routings for each type of cable.

The different cable trays on a site are designed for:

- High voltage
- LV power circuits
- LV control circuits
- Control instrumentation (4-20mA, etc.)
- Low current instrumentation (thermocouples, etc.)
- Distribution bus instrumentation
- Telephony
- IT
- The earth of the equipment grounds (where applicable)
- etc.

All these cables and circuits are routed and cross over each other according to predetermined rules.

Therefore, when on site, please do not ask to add a cable to power your computer or control room TV by running your cable along a lightning conductor drop stack, for example, claiming that it is more convenient. (There is a good reason for this… ask your instructor for an explanation if you do not understand why).



You may get a few surprises: "*why does the compressor cut out when we start the transfer pump?"* If the vibration sensor cable or thermocouple cables pass close to the pump's 6 kV cable, it is not surprising. (Other phenomena may very well not give any indication of what triggers the fault in the case of rapid transient induction.)

Cable trays are made of different materials (galvanised steel, stainless steel, fibre glass, PVC, etc.), different constructions (wire, ladder, perforated, etc.) and a wide range of colours, etc. Troughs, conduits and tubes (steel or PVC) are all similar to cable trays since they support/guide wires or cables.

Figure 85: Different types of cable trays

In addition to providing mechanical protection, the **covers** of cable trays are mainly used to protect cables from the aggression of UV which damages the outer insulation sheath over time.

7.2. LAYING CABLES

The following tips concern aligning cables on cable trays.

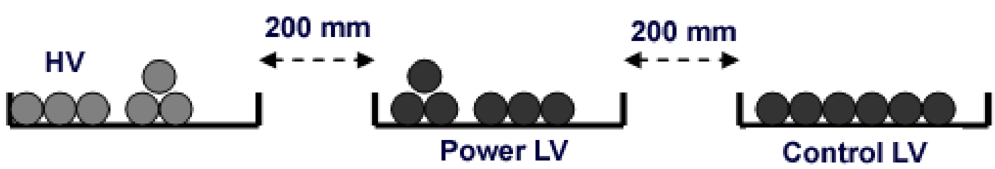


Figure 86: Horizontal distances between cable trays

Whether the cable trays are laid ***vertically or horizontally***, a minimum installation distance must be maintained between the different types of cable trays.

A distance of 200 mm is frequently used. However, check the correct specifications, as this may not be the case.

Cable trays are mechanically and electronically splinted together using a ground conductor connected to the general earth. This includes PVC and fibre glass cable trays (static electricity!)

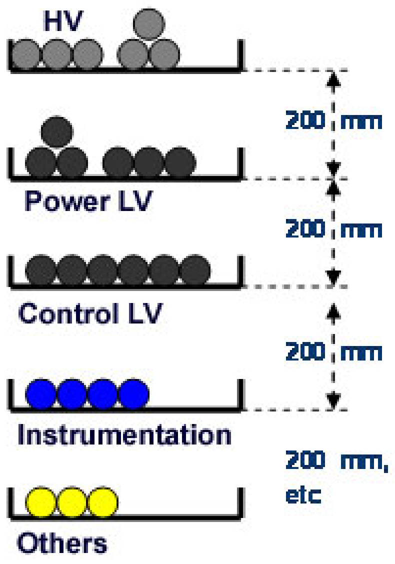


Figure 87: Distances between cable trays when installed vertically

Trefoil (clover leaf) or aligned configurations

This concerns power cables. The conductors of a cable carrying three phase current are manufactured twisted together to cancel (or rather to minimise) the electromagnetic induction produced by each phase (imagine the 3 vectors at 120°, their vector component is zero).

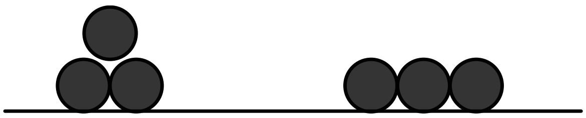


Figure 88: Trefoil or aligned configurations

Three-phase cables (or three + N) may be laid either aligned or in a trefoil configuration. However, for high powers, when several single-pole cables form one phase, the trefoil technique must be used, the 3 conductors in the trefoil represent the 3 phases.

As a general rule, the ***cables*** must not be just "thrown" on the cable trays but ***aligned and attached***. This is not just because it looks better but is also for maintenance purposes (it is easier to add/remove a cable) and to reduce the induction phenomena.

If you find cables which are heating up, or even a hot cable tray, this is not necessarily due to a current overload, it may simply be because the cables are incorrectly laid…

7.3. LADDER RACK

Ladder rack (also known as "cable ladder" or "ladder cable tray")is a quick and easy method of transporting heavy-duty cables over long distances and in the worst site conditions since it can withstand high winds, heavy snow, sand or dust buildup, or high humidity.

The ladder is very strong and can be mounted in virtually any direction.
Ladder rack is made of hot dipped galvanised steel.

It can often be used in conjunction with a cable tray on an installation.

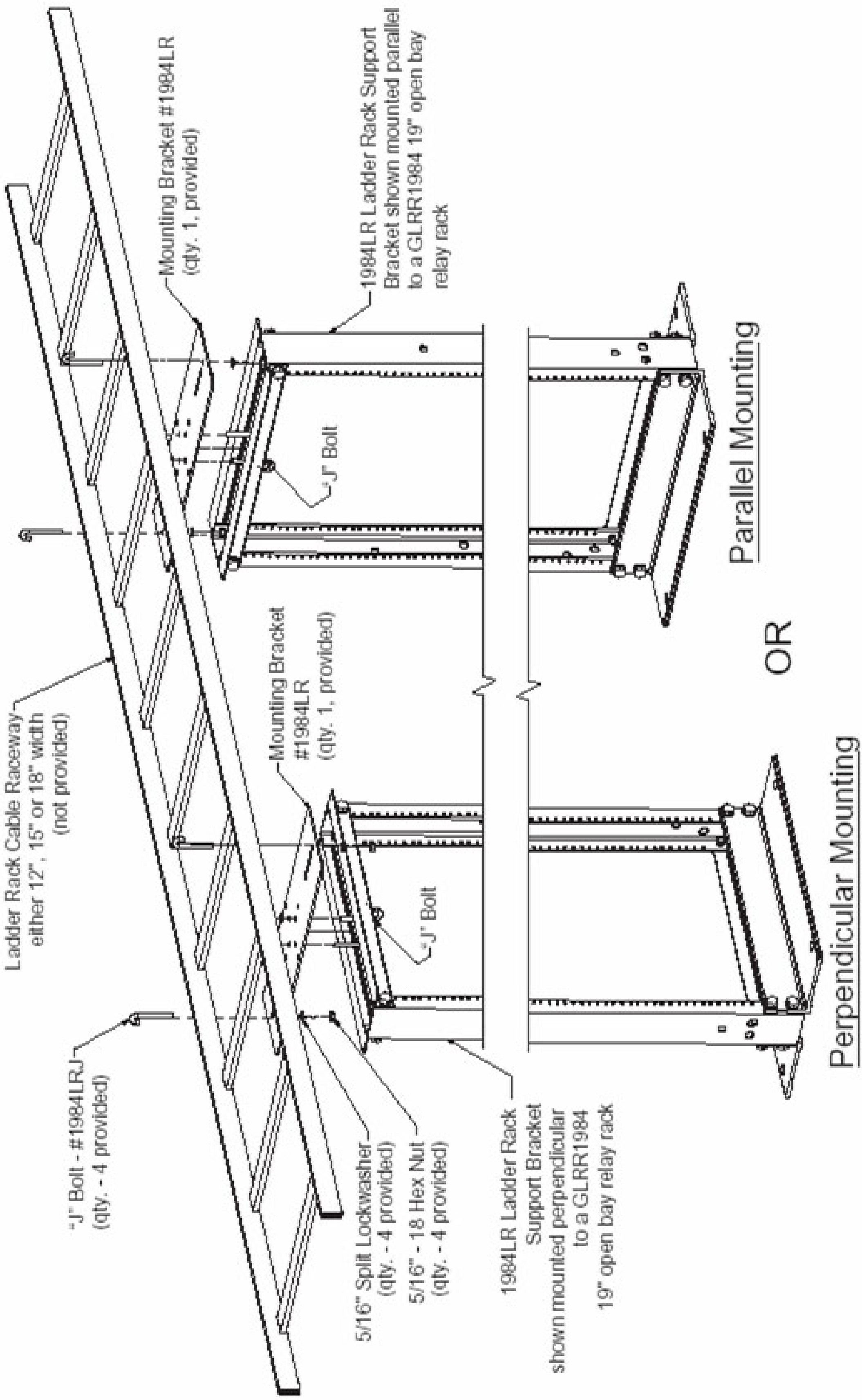


Figure 89: Ladder rack

You can find ladder rack supports on site in switchgear/MCC electrical rooms and they are even very often found in the basement of those rooms.

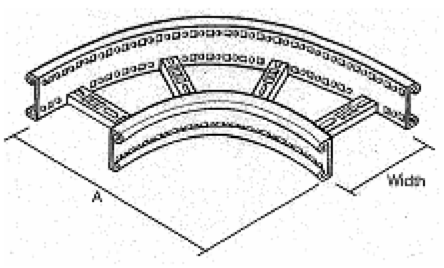
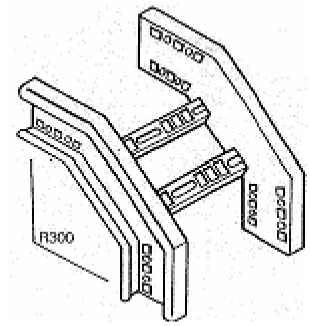
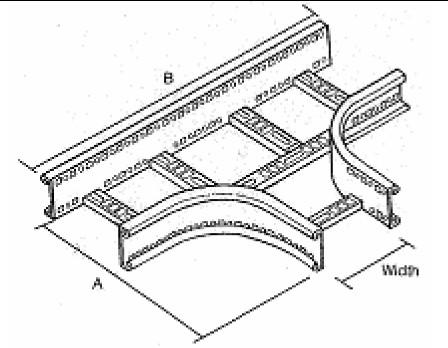
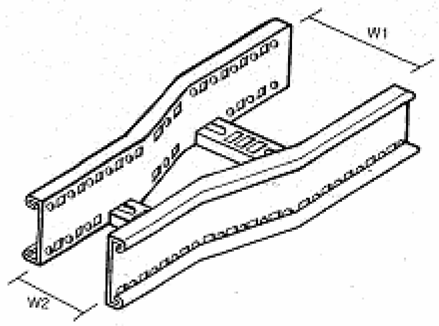
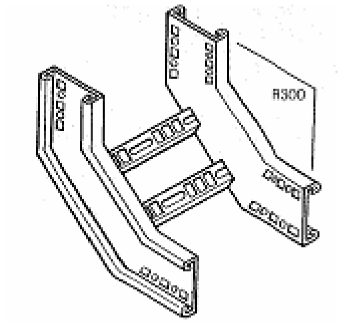
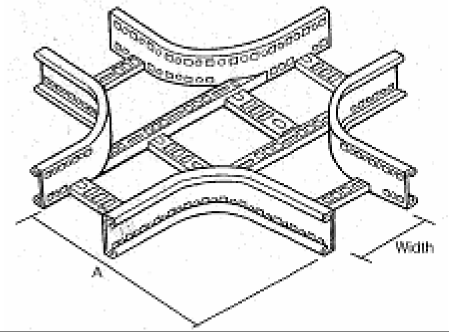
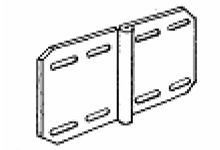
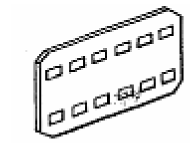
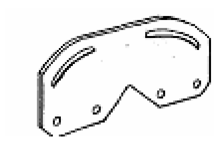
Ladder rack accessories		
		
90° Bend	90° Outside Upright	Equal Tee
		
Straight Reducer	90° Inside Upright	Equal Crossover
		
Horizontal Hinged Coupler	Flat Coupler	Vertical Coupler

Table 11: Ladder rack accessories

7.4. THE DIFFERENT TYPES OF CABLE TRAYS

7.4.1. Types of cable trays available

- Ladder
- Solid bottom
- Trough
- Channel
- Wire mesh
- Single rail

7.4.1.1. Ladder cable trays

Ladder cable trays provide:

- A solid side rail protection and good system strength with smooth radius fittings and a wide selection of materials and finishes

Figure 90: Ladder cable trays

.

- Maximum strength for long span applications with standard widths.
- Standard depths
- Standard lengths.
- Rung spacing.

Standard dimensions depend on the countries and the manufacturers.

7.4.1.2. Solid bottom cable trays

Solid bottom cable trays provide:

- Nonventilated continuous support for more fragile cables and an added protection for the cables made of metal or fibreglass.
- Solid metal bottom with solid metal covers for cables installed in overhead zones.
- Standard widths
- Standard depths
- Standard lengths

Figure 91: Solid bottom cable tray

Standard dimensions depend on the countries and the manufacturers.

Solid bottom cable trays are generally used for electrical or telecommunication applications generating minimal heat and for computer applications with short to intermediate support spans.

This type of tray is not recommended for use on sites due to the lack of ventilation afforded.

7.4.1.3. Trough cable trays

Trough cable trays provide:

- Moderate ventilation with added cable support frequency and the configuration of the bottom part allows cable supports/tying at very short distances. Available in metal and nonmetal materials.

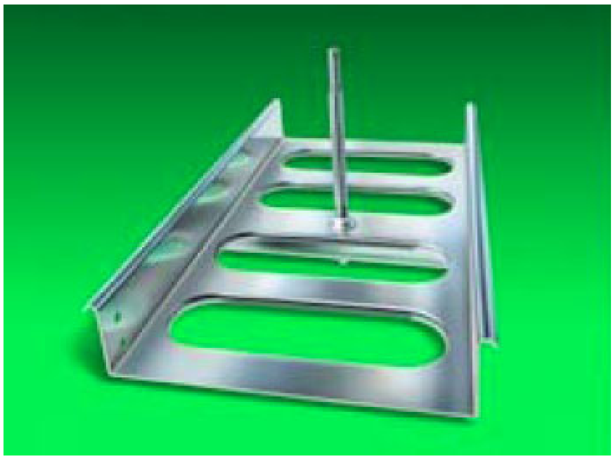


Figure 92: Trough cable trays

- Standard widths
- Standard depths
- Standard lengths
- Fixed rung spacing at the centre

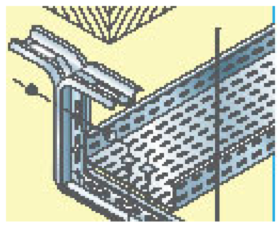


Figure 93: Perforated cable trays

Standard dimensions depend on the countries and the manufacturers.

Trough cable trays are generally used for applications generating moderate heat with short to intermediate support spans of 1.5 to 3 m.

The perforated cable tray is also a type of trough cable tray.

7.4.1.4. Channel cable trays

Channel cable trays provide:

- Cost-effective support for cable drops and branch cable runs from the backbone cable tray system.

- Standard widths in metal and nonmetal systems.
- Standard depths in metal systems and 1 depth in a nonmetal system
- Standard lengths.

Figure 94: Channel Cable Tray

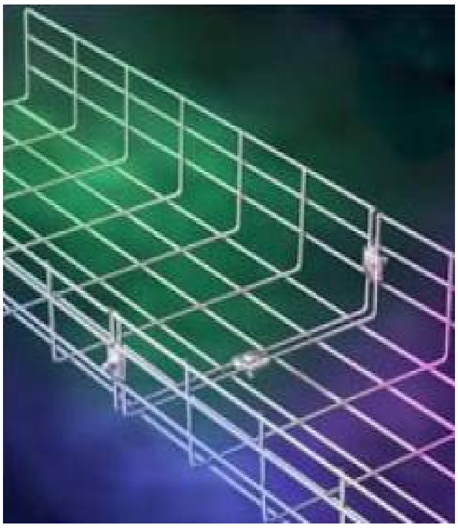
Standard dimensions depend on the countries and the manufacturers.

Channel cable trays are used for installations with limited numbers of cable in the tray when conduit is undesirable.

Support frequency with short to medium support spans of 1.5 to 3 m.

7.4.1.5. Wire mesh cable trays

Wire mesh cable trays provide:



- A field-adaptable job site support system primarily for low voltage, telecommunications and fibre optic cables. These systems are normally made of zinc plated steel wire mesh.

Figure 95: Wire mesh cable trays

- Standard widths
- Standard depths
- Standard lengths

Standard dimensions depend on the countries and the manufacturers.

Wire mesh trays are generally used for telecommunications and fibre optic applications and are installed on short support spans of 1 to 2 m.

7.4.1.6. Single rail cable trays

- These aluminium systems (other materials are now used) are the fastest systems to install and provide maximum freedom for the cable to enter and exit the system.

- Single-hung or wall mounted systems in single or multiple tiers.

Figure 96: Single rail cable trays

- Standard widths

- Standard depths

- Standard lengths

Standard dimensions depend on the countries and the manufacturers.

Single rail cable trays are generally used for low voltage and power cable installations where maximum cable freedom, side fill and fast installation are important factors.

7.4.2. Materials / finishes available for the various cable tray systems

- **Steel** (Min. Yield = 33KSI) (35 KSI for stainless steel)

  Solid: hot rolled pickled and oiled steel as per ASTM A569 (Commercial Quality) or A570 (Structural Quality).

  Pregalvanised: galvanised milled steel as per ASTM A653 CS (Commercial) or SS (Structural Quality) G90

  Hot dip galvanised after fabrication: black steel which is hot dipped after fabrication as per ASTM A123.

  Stainless steel: type 304 or 316L fully annealed stainless steel.

- **Aluminium** (Min. Yield = 23 KSI)

  Alloy 6063-T6 or 5052-H32 as per ASTM B209.

- **Fibre-Reinforced Plastic (FRP)**

  Polyester and Vinyl Ester resin systems available.

Meets ASTM E-84 smoke density rating; Polyester 680, Vinyl Ester 1025.

Class 1 flame rating and self-extinguishing requirements of ASTM D-635.

7.4.3. Cable tray mounting accessories

It is impossible to show all the items which could be used for the different types of cable trays, it would require a 200-page catalogue.

Here are some examples.

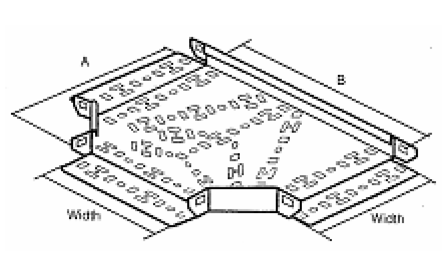
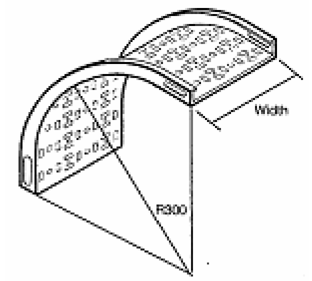
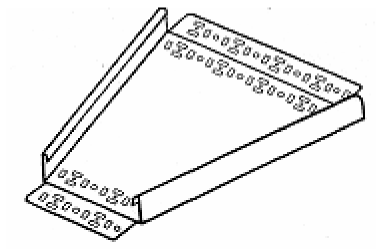
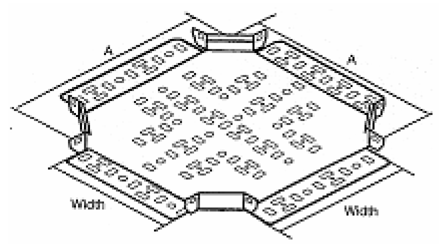
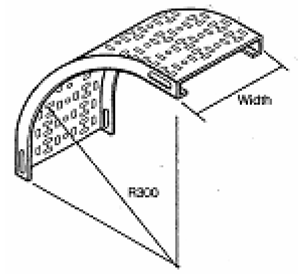
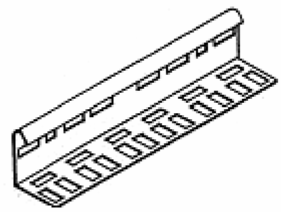
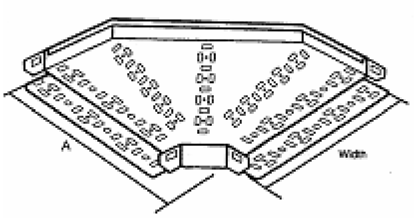
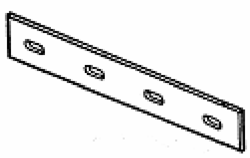
Accessories for cable trays		
		
Equal Tee	90° Outside Riser	Straight Reducer
		
Equal Crossover	90° Inside Riser	External Wrap-over Coupler
		
90° Bend	Internal Short Coupler	

Table 12: Accessories for cable trays

When these accessories are unavailable, the following methods are recommended for the construction of various bends and junctions. It should be noted that all cuts in the metal should be painted with a rustproof paint.

7.4.4. How to construct a flat 90° bend

The first step is to mark out the tray (A).

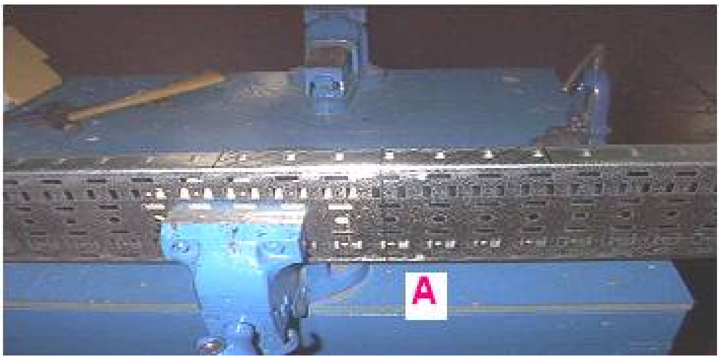


Figure 97: Construction of a flat 90° bend (A)

The amount of tray lip to be removed is equal to 2, 3/4 the width of the tray, half of this measurement will be removed on either side of the centre line.

To remove the lip we can use a small hand grinder (B) or a file (C), but care must be taken when using a hand grinder to ensure that the protective equipment is in good condition.

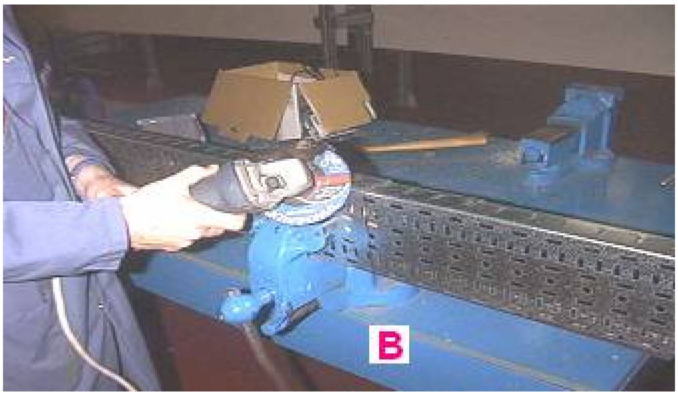


Figure 98: Construction of a flat 90° bend (B)

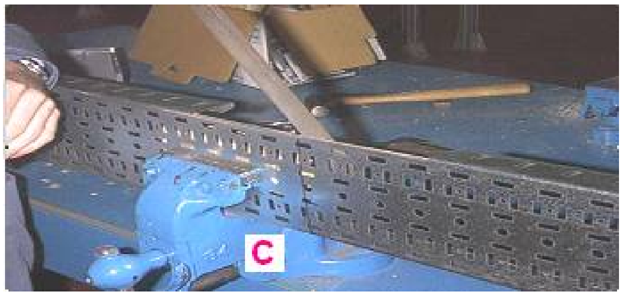


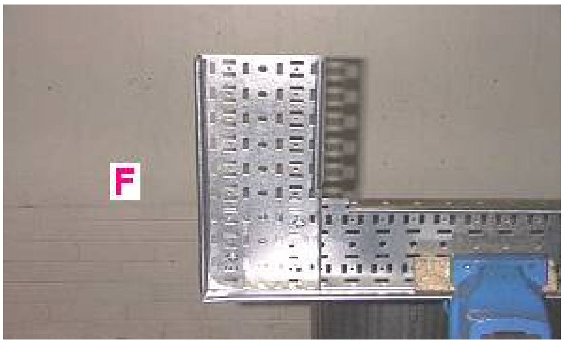
Figure 99: Construction of a flat 90° bend (C)

Next we cut down the centre line, care must be taken not to let the tray fall open at this point as it may be damaged (D).

Figure 100: Construction of a flat 90° bend (D)

Now use a blunt object to flatten the tray lip at the point where the tray will be bent (E).

Figure 101: Construction of a flat 90° bend (E)



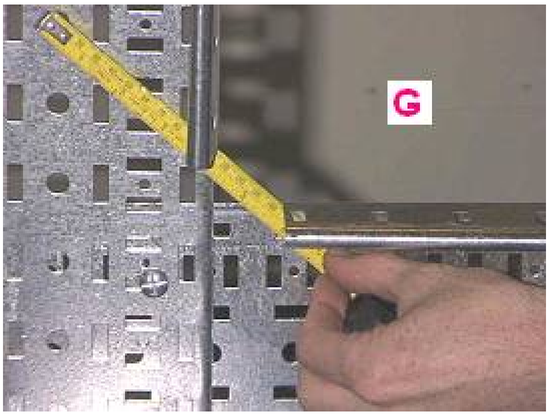
Then bend the tray to 90° and bolt the two parts together (F)

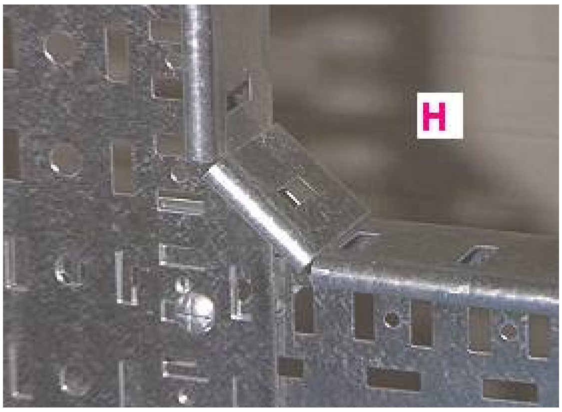
Figure 102: Construction of a flat 90° bend (F)

Now we measure the distance between the 2 internal edges (G).

This will be the measurement for our gusset.

Figure 103: Construction of a flat 90° bend (G)



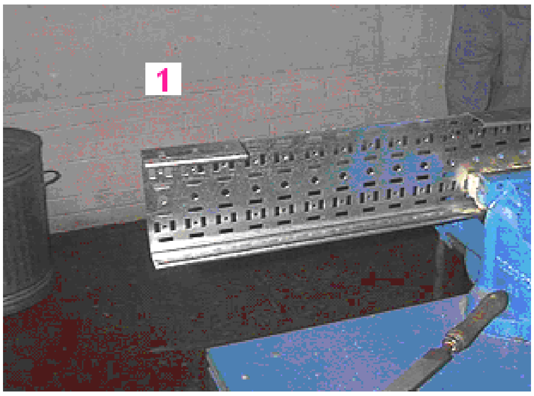


The gusset is produced by cutting a piece of tray to the required size, removing 1 lip completely and bolting it to the 90° bend (H).

Figure 104: Construction of a flat 90° bend (H)

This completes the 90° bend.

7.4.5. How to construct a Tee piece



The first step is to mark and remove the tray lip (1).

This measurement is equal to twice the width of the tray.

We also remove one and a half times the width of the tray from the piece of tray to be added to the Tee.

Figure 105: Construction of a Tee piece (A)

The 2 pieces of tray are now bolted together (2).

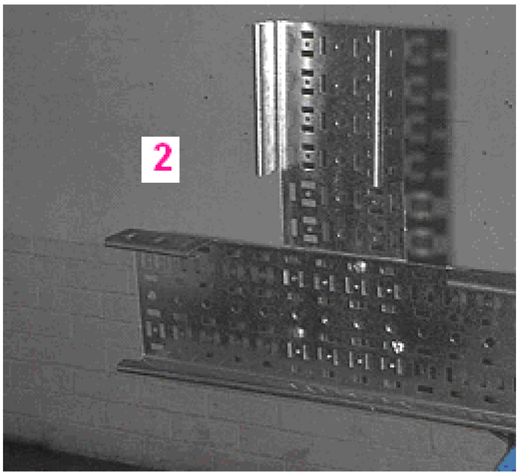
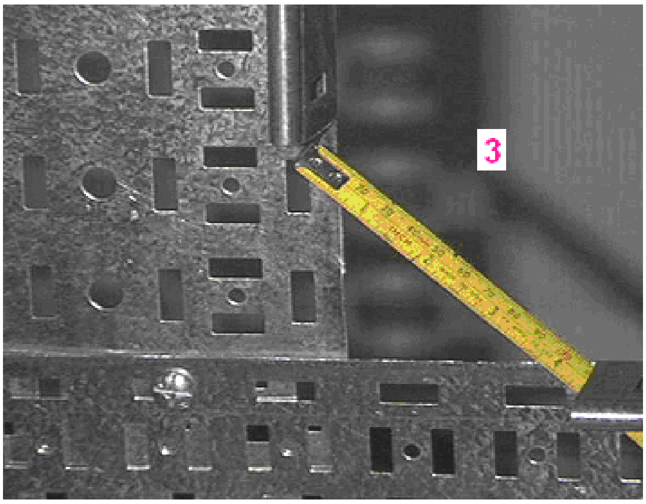


Figure 106: Construction of a Tee piece (2)



Next we measure the gussets (3)

Figure 107: Construction of a Tee piece (3)

Once the gussets have been made, the final step is to bolt the tray together and produce a Tee piece (4).

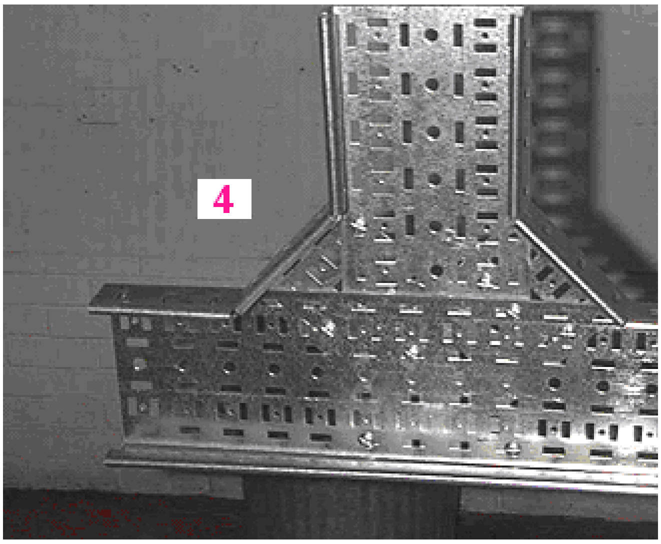


Figure 108: Construction of a Tee piece (4)

7.4.6. How to construct a 90° external bend

This is perhaps the easiest bend to make. We first mark out the tray (a).

The lines are drawn 75 mm apart, we cut down all 3 lines on both sides of the tray and bend to 90° as shown in figures (b) and (c).

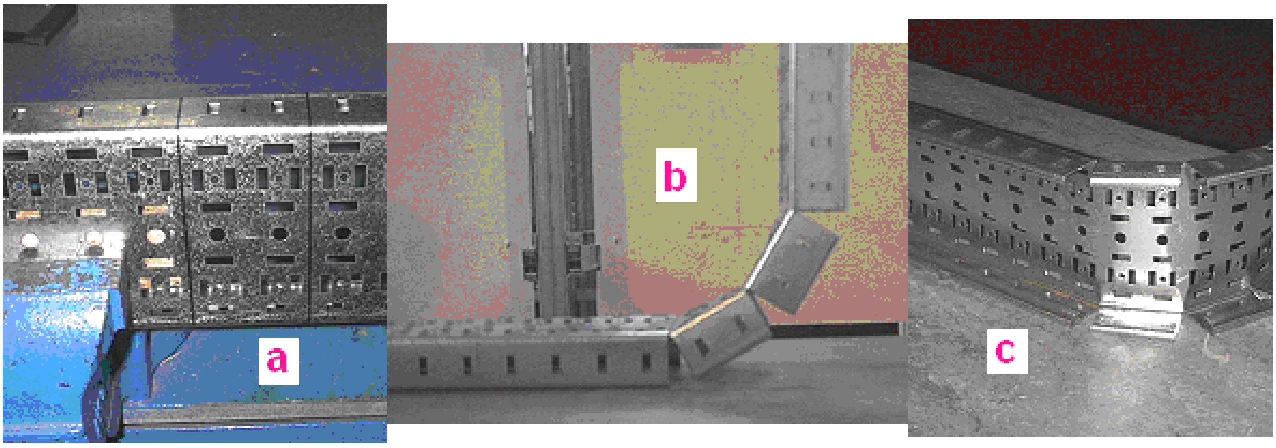


Figure 109: Construction of a 90° external bend

To make bending the tray easier, try using a round object such as a scaffold tube, handrail, etc.

7.4.7. How to construct a 90° internal bend

We first mark and remove the tray lip (1). The lines are drawn 75 mm apart. Next we measure 12 mm on either side of each of these 3 lines, draw 2 diagonal lines from point A to B and point A to C on all the lines and on both edges of the tray and remove them. Then bend to 90° (2).

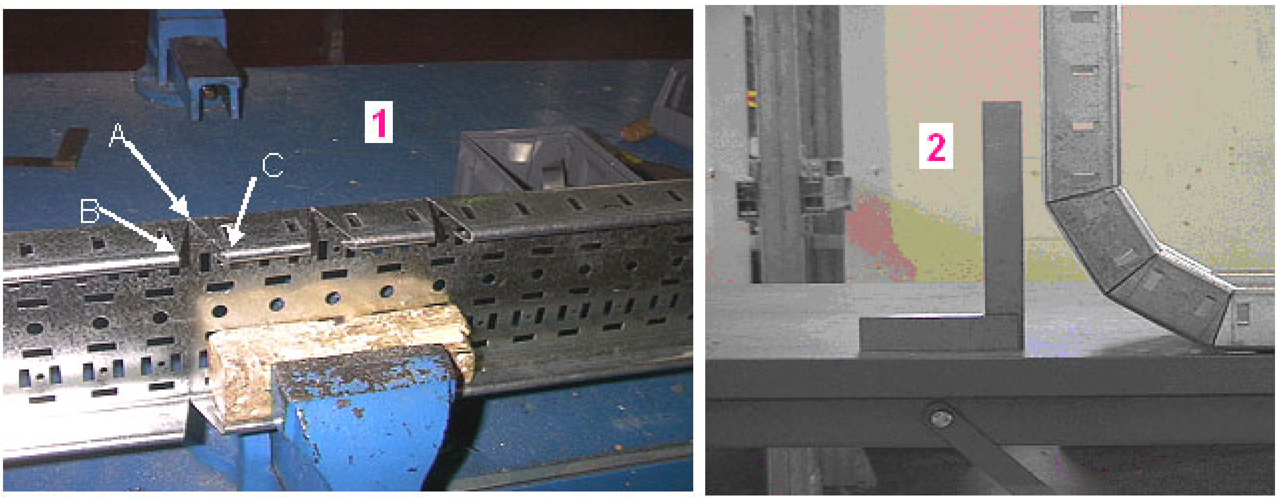
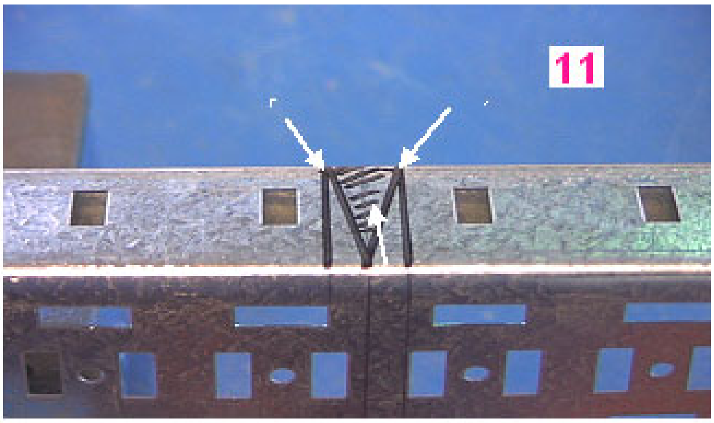


Figure 110: Construction of a 90° internal bend

7.4.8. How to construct an offset

First mark the tray (11), draw a centre line, measure 10 mm approx. on either side of the centre line and draw 2 lines.

Now draw 2 diagonal lines from point A to point B and from point A to point C and remove as shown in figure (12).



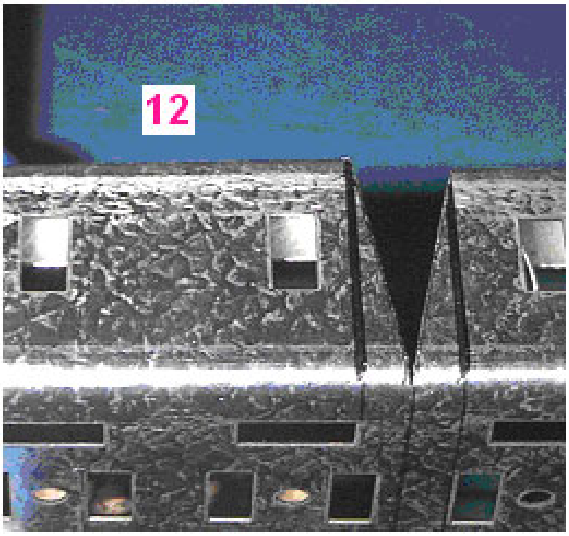
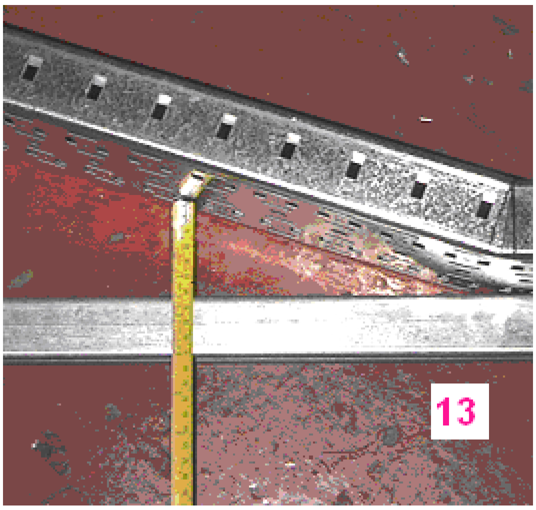


Figure 111: Construction of an offset (11) and (12)

Then bend the tray and measure the size of the required offset (13)



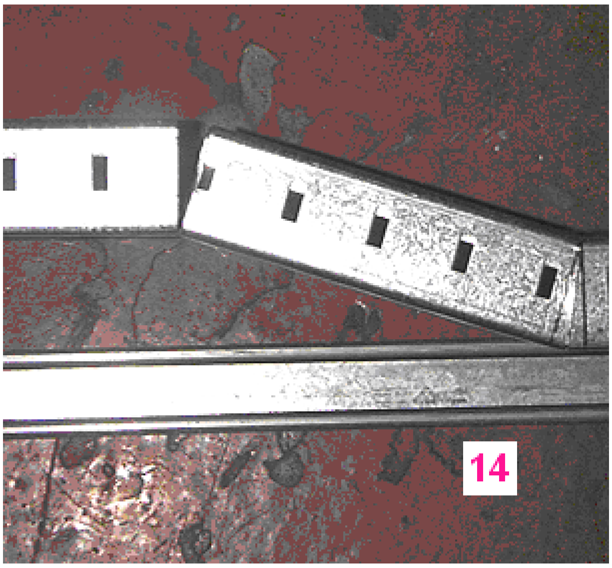


Figure 112: Construction of an offset (13) and (14)

Once the size of the offset has been determined, mark out the cut on both edges, then bend to the required shape (14).

When the bends and offsets have been completed, all cuts must be painted with a rustproof/corrosion-proof paint.

Those “operations” were carried out on a perforated galvanised steel cable tray, the procedure would be almost identical with a stainless steel or fibre cable tray.

7.4.9. Earthing the cable trays

Whatever the type of metal cable tray, it must be earthed:

- To the plant's general earthing system every 15 to 20 m.
- To the plant's general earthing system at its ends if the length is less than 15 m.
- All along the earthing wire connected with specific studs to ensure electrical continuity between the lengths. (as shown in the figure)

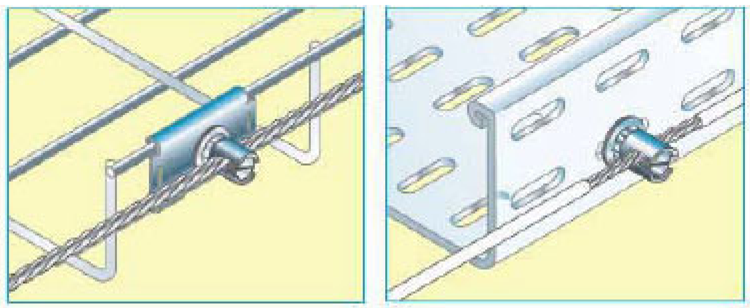


Figure 113: Earthing a cable tray

Also see the Company Standards on this point.

8. LOW VOLTAGE CABLES

Electricity flows from the supply to the load through cables. Cables are an integral part of all circuits. Every cable has to be connected to some part of the circuit.

The connection of a cable to any part of the circuit is called a termination. There are many different types of terminations for different conditions and equipment.

The aim here is not to develop the complete technology of terminations inside cubicles, panels and junction boxes, but only to show the accessories such as lugs, terminals and tools to use, etc. If a termination is not made correctly it can cause a lot of problems. A bad termination may overheat and start a fire. A connection may have a very high resistance which can cause problems with the power supply to the equipment.

For the “other accessories”, i.e. the cable glands, the cable trays, the wall crossings, and the different cable laying devices, see next chapter. This present paragraph covers the most common types of cable terminations.

Cable terminations are an important part of the electrician's job. Therefore they must be made correctly using the right tools and equipment.

8.1. CABLE TERMINATIONS

The connection of a cable inside a device or piece of equipment is called a termination. All electrical terminations must be both electrically and mechanically secure.

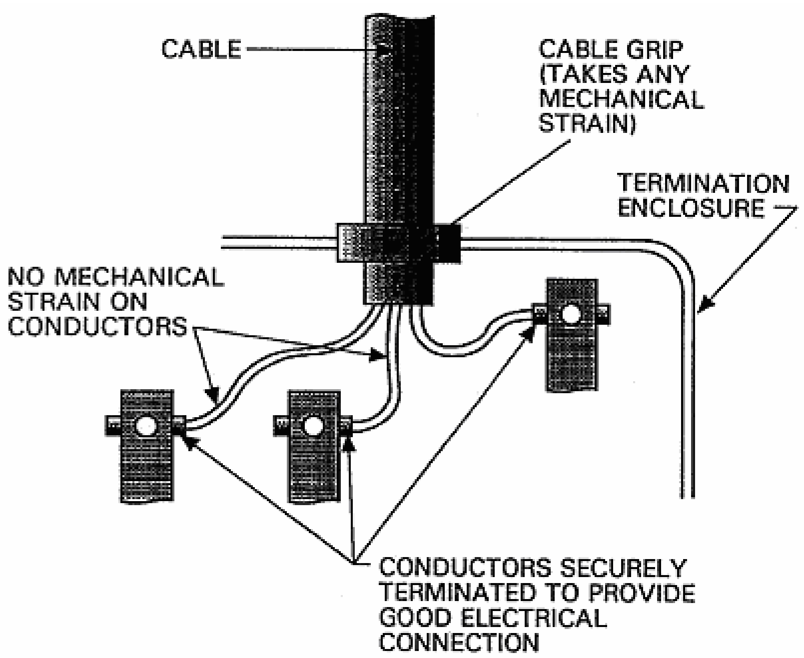


Figure 114: Cable termination.

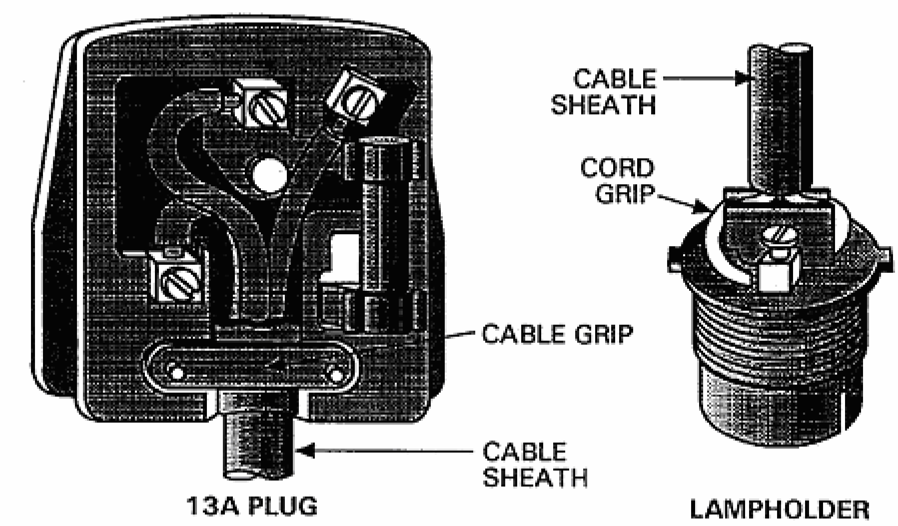
The termination must be good enough to carry the load current of the circuit.

This means that the connections must have a low resistance and the cable must be tightly secured.

There should be no mechanical strain on the conductor connections.

The cable should be held firmly in the termination enclosure by a cable grip. Any mechanical strain should be on the cable grip, not on the conductors.

Different types of cable grips guarantee the level of mechanical strain exerted on the termination.



Here are some special cable glands, collars and tension reducers adapted to different types of cables and termination enclosures.

Figure 115: Types of cable grips used on small household appliances.

If the conductors in the termination are under mechanical strain then they may become loose. A loose connection could overheat and cause a fire or it could disconnect and break the circuit.

It is important that all terminations meet the following conditions:

- A termination should be electrically and mechanically secure.
- The cable sheath should be intact and undamaged right up to the termination enclosure.

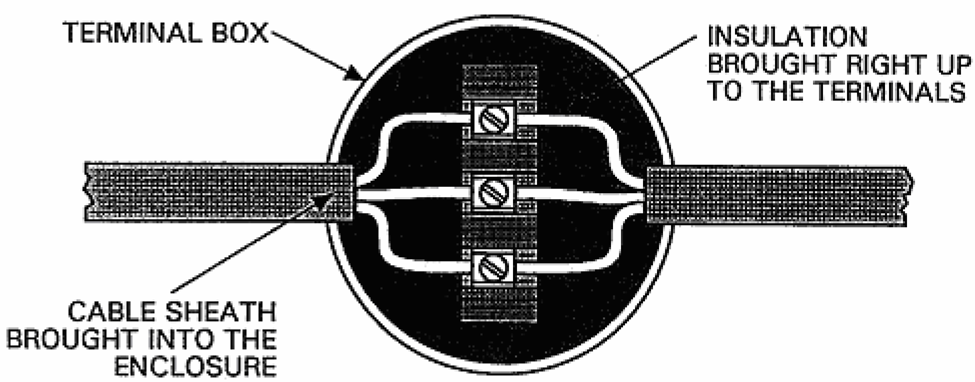


Figure 116: Terminal connections

- There should be little or no mechanical strain on the termination conductor connections.

- The insulation should be intact and undamaged right up to the terminals
- All the conductor's strands must be intact and securely held in the termination. No loose wires.

8.2. REMOVING THE INSULATION

Before a conductor can be terminated, the cable insulation must be removed. Removing the sheath and insulation from a cable is called stripping the cable. Cable stripping can be done using side cutting pliers or a stripping knife.

8.2.1. Removing the sheath using side cutting pliers

1. Split the sheath along the length of the cable. Be careful not to damage the insulation of the wires.

2. Peel back the sheath and cut away the unwanted portion. (See figure 14-4).

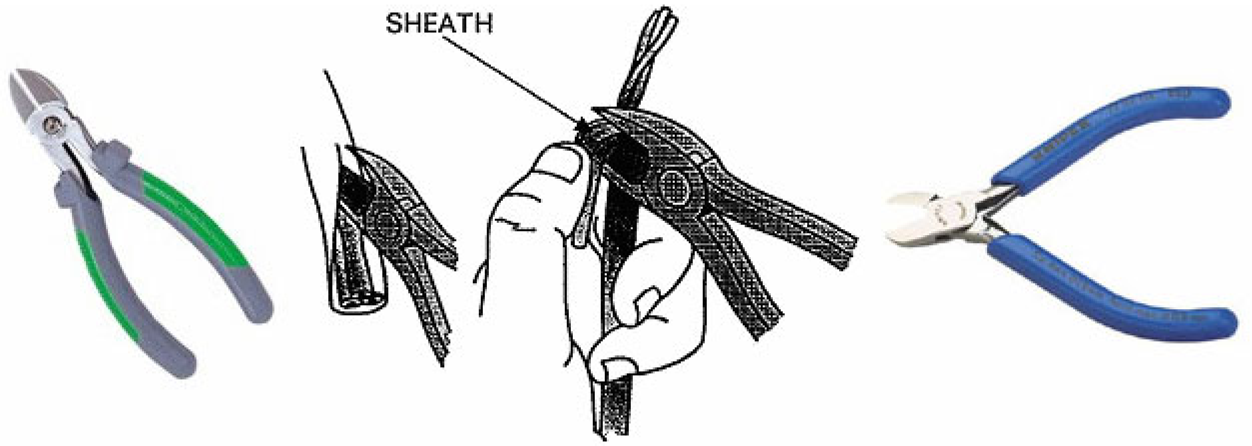


Figure 117: Cut away the unwanted portion of the sheath

3. Check the conductor insulation for damage.

4. Where there are two or three layers of protection, they must be removed separately.

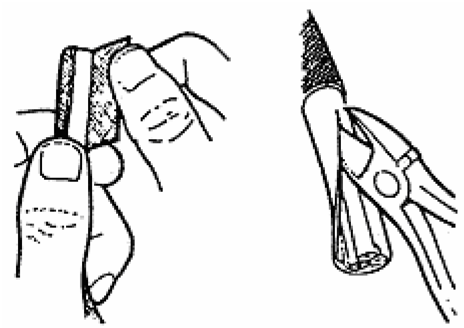


Figure 118: Remove each layer of protection separately.

8.2.2. Stripping insulated wires with a stripping knife

The insulation around a wire (conductor) can be stripped with a stripping knife.

A stripping knife should have a short, wide blade with a flat end.

Figure 119: Typical electrician's stripping knife

It is important to hold the knife at an acute angle when cutting the insulation.

Make two or three cuts from different sides of the wire. Then pull off the unwanted insulation with a pair of pliers.

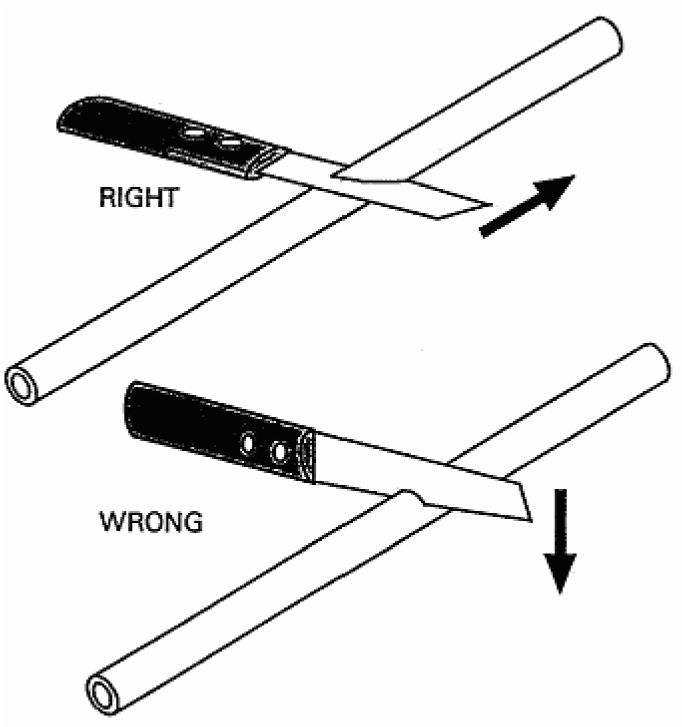


Figure 120: Cutting the insulation with a knife

Do not cut into the conductor

A conductor with a nick (small cut) in it is doubly dangerous.

1. It will break after it has been bent a few times.

2. The cross-sectional area will be smaller so the resistance in that part of the conductor will be higher. This can cause overheating.

Use wire strippers to strip wire where possible. They do a cleaner, better job.

8.2.3. Wire stripping tools

You can use a special kind of pliers to remove the insulation from a wire. The jaws have V-shaped notches. When the jaws are closed the notches form a hole. You can adjust the jaws so that they only cut the insulation. When correctly adjusted they do not cut the wire.

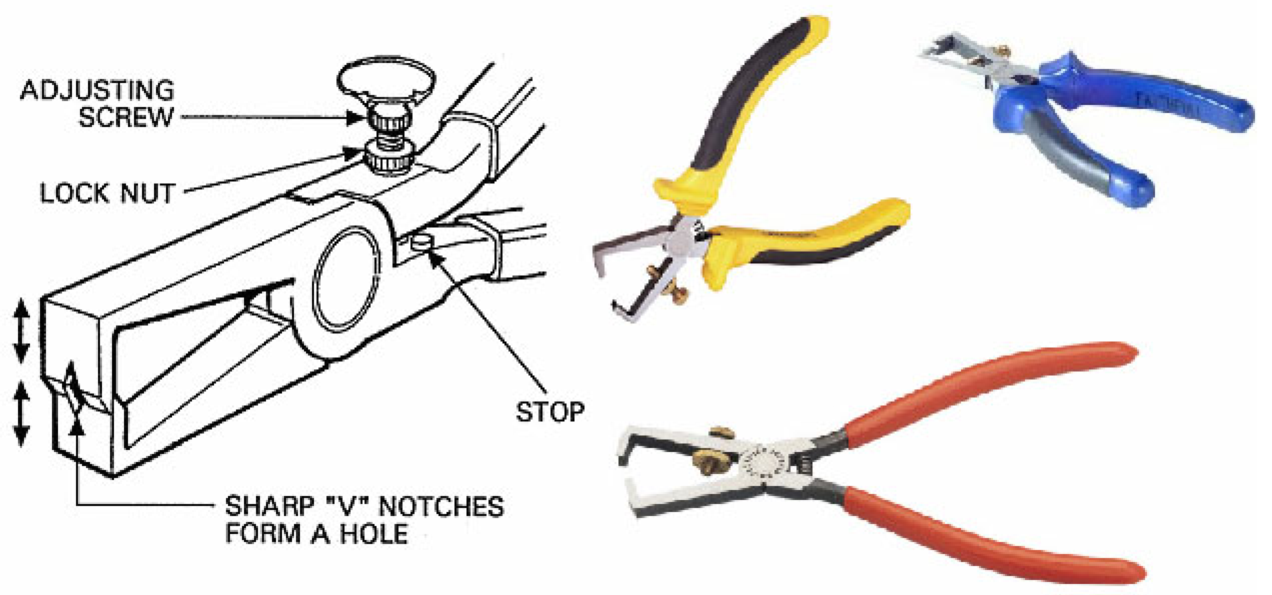


Figure 121: Adjustable wire stripping pliers

How to use wire strippers.

1. Turn the adjusting screw so that the grip in the jaws corresponds to the right wire diameter.

2. Tighten the lock nut.

3. Place the wire in the V of the bottom jaw and close the pliers on the wire (Part (A) in the figure).

4. Turn the pliers and pull the wire out of the jaws to remove the insulation (Part (B) in the figure).

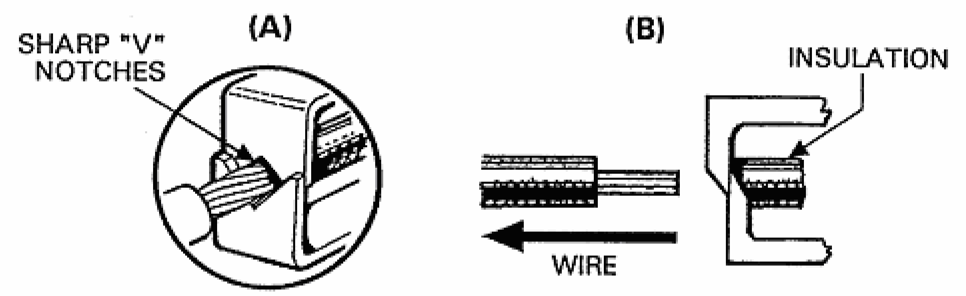
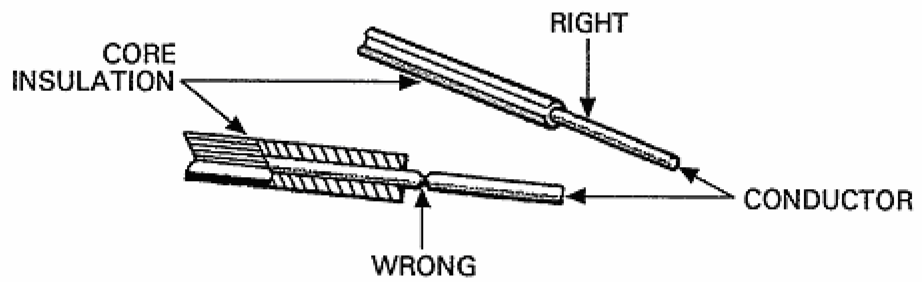


Figure 122: Using wire strippers

There are other kinds of wire stripping tools which work on the same principle. When the jaws close they form a hole so that they only cut the insulation. They leave the wire intact.

See the “Automatic stripping pliers” pictures. Some tools even combine the stripping and crimping functions, but only for small wire cross-sections.

Figure 123: Set of automatic stripping (stripping and crimping) pliers



After the insulation has been removed, check that the conductor has not been damaged.

Figure 124: Check the state of the conductors

A conductor which has been damaged will break easily or it will increase the resistance in the wire. So you must be careful not to damage the conductor when removing the insulation.

If the cable has a stranded conductor then the strands should be twisted together tightly before making the termination. Use pliers (flat nose pliers preferably) to twist the strands in the direction of the existing twist (lay) of the cable.

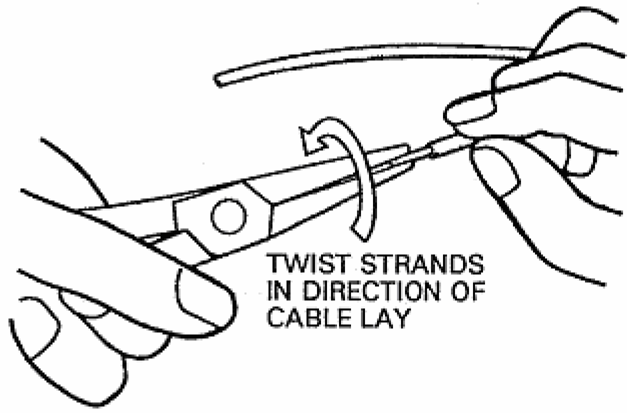


Figure 125: Preparing a stranded cable

You must make sure that all the strands are fitted into the termination.

If not, the current carrying capacity of the cable will be reduced. Also, loose strands in the termination can cause short circuits.

8.3. TYPES OF TERMINATIONS AND CONNECTIONS

There are many different ways of joining or terminating conductors. The different methods of termination are divided into two groups:

- Heated terminations (e.g. brazing, soldering)
- Mechanical terminations (clamping, bolting, etc.)

This paragraph will cover mechanical terminations only.

8.3.1. Mechanical terminations

The advantage of mechanical terminations is that they are strong but the connection is not permanent. It can therefore be taken apart easily for repairs or changes to the circuit.

The disadvantages are that the terminals can oxidise and screwed joints can become loose over a period of time *(This is why you need regular maintenance operations to retighten the connections)*.

The most common types of mechanical terminations are:

- Pillar Terminals
- Screw Terminals
- Nut and Bolt Terminals
- Strip Connectors
- Claw washers
- Split bolt connectors

8.3.1.1. Pillar terminals

You often see pillar terminals in the plugs on household appliances.

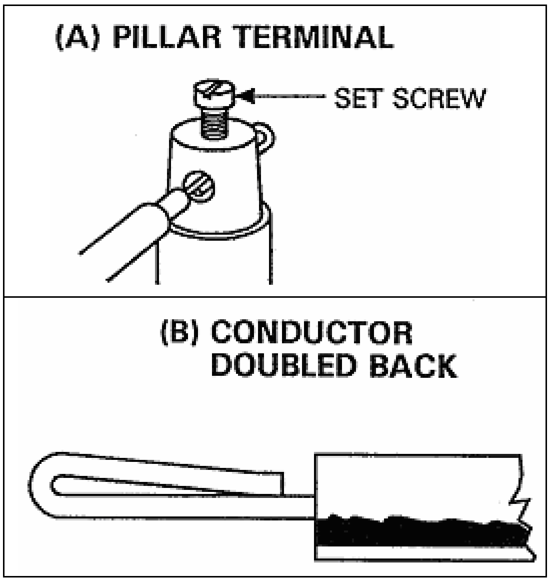


Figure 126: Pillar Terminal

A pillar terminal has a hole through the side where you insert the conductor. A set screw is tightened onto the conductor.

If the conductor is small in relation to the hole, it should be doubled back.

You can put two or more conductors in the same terminal by twisting them together.

You must be careful not to damage the conductor by tightening the set screw too much.

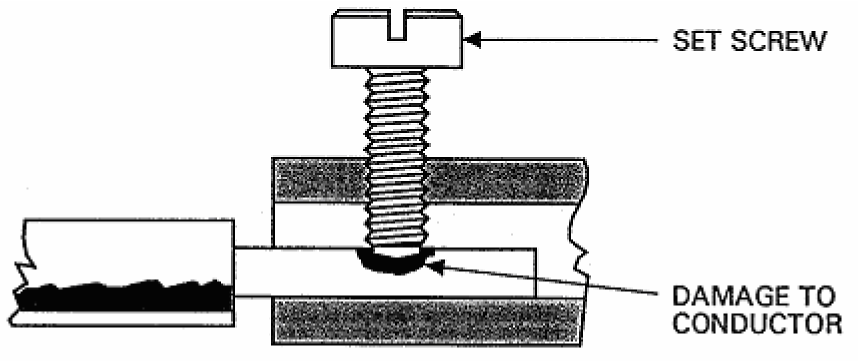


Figure 127: Overtightened set screw

8.3.1.2. Screw terminals and nut-bolt terminals

When fastening conductors under screw heads or nuts the conductor should be formed into a loop. You can do this easily using round-nosed pliers.

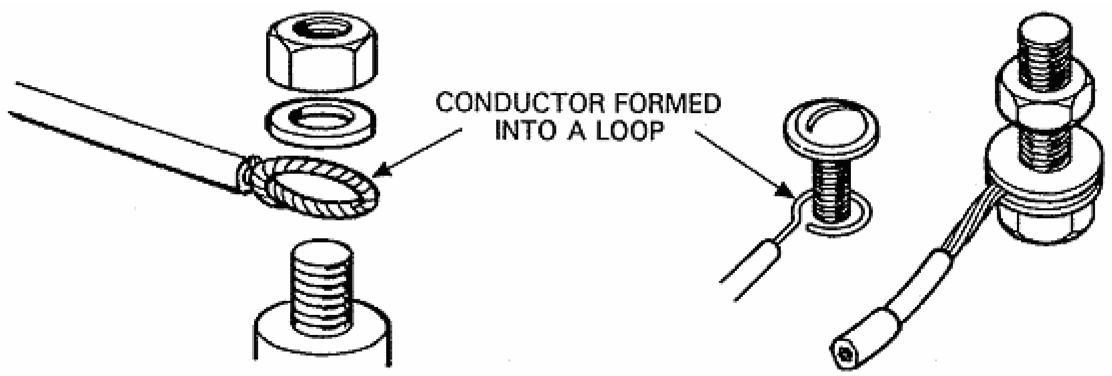


Figure 128: Screw terminal and nut-bolt terminals

The loop should be placed so that when you tighten the screw or nut you do not cause the loop to open.

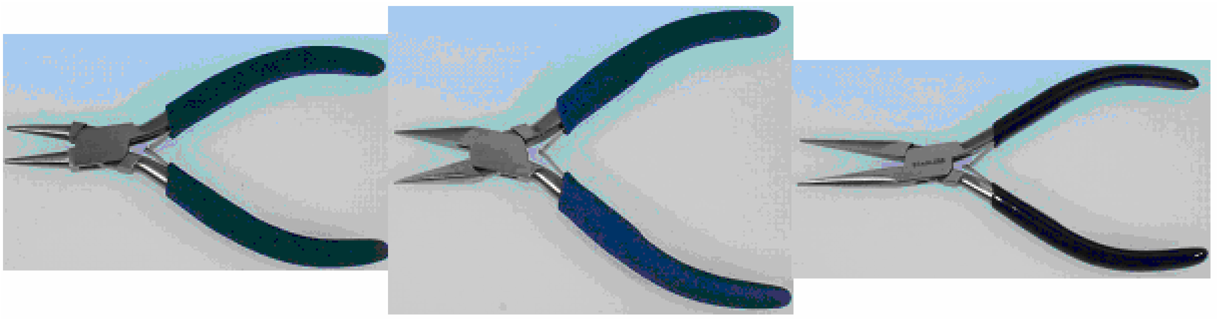


Figure 129: Round nosed – half nosed – long and short nosed pliers

8.3.1.3. Claw washers (also know as toothed washers)

You can use a claw washer to prevent the loop from opening when you tighten the screw.

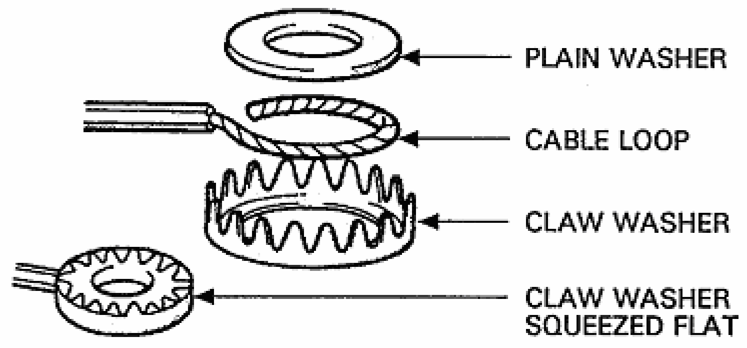
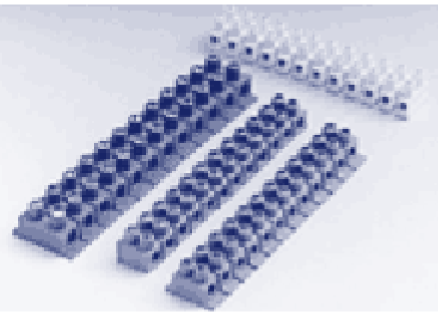


Figure 130: Claw washer

Place the plain washer on top of the loop. Then place both the loop and the plain washer on the claw washer. Tighten until the metal teeth of the claw washer are flat on the terminal loop.

8.3.1.4. Strip connectors



Strip connectors are sometimes called terminal blocks. Strip connectors are a group of brass connectors fitted in a line in a moulded insulated block.

Figure 131: Strip connectors in moulded blocks

The conductors are held in place with a grub screw in the same way that a set screw grips the conductor on a pillar terminal.

The conductors should be pushed well into the connector.

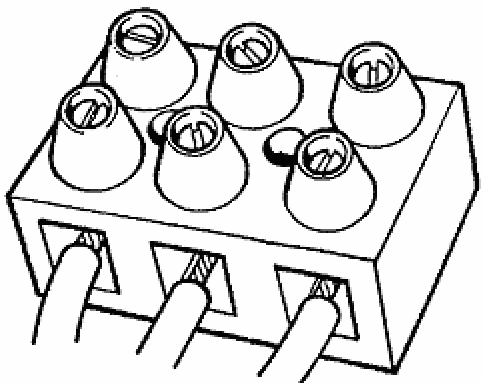
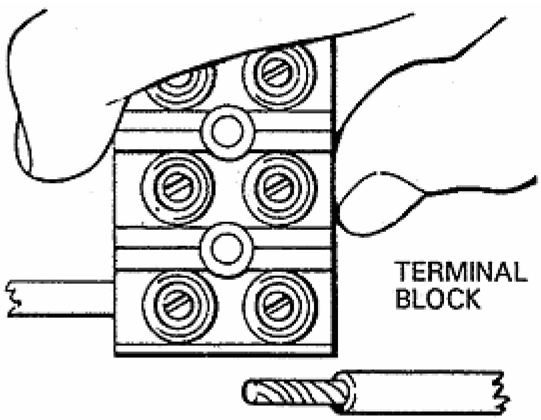


Figure 132: Connections on a strip connector

This prevents the grub screw only gripping the end of the conductor.



It is important to get a good, clean, tight connection.

This will prevent high resistance contacts which would cause the connection to overheat.

It will also prevent loose contacts which might come apart.

Figure 133: Inserting a conductor into a terminal block

Some connectors have pressure plates which produce better connections.

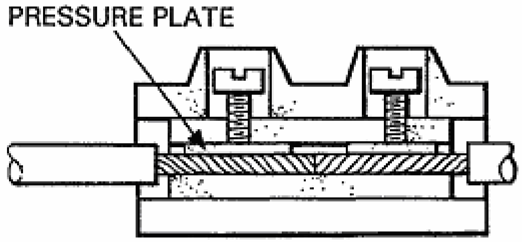
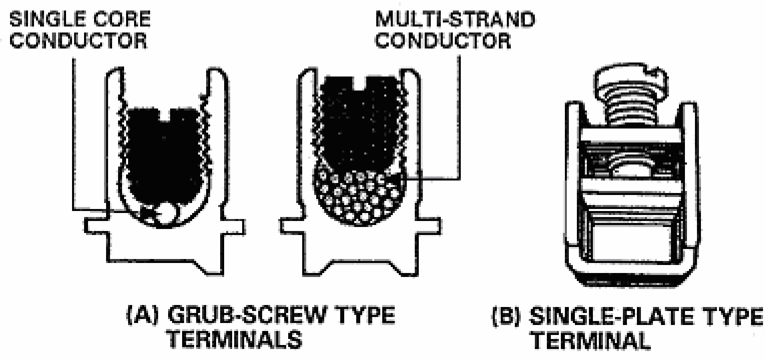


Figure 134: Pressure plate terminal block

A pressure plate spreads the pressure over the connection and provides a better contact between the two conductors.

This is especially important when you are dealing with high current circuits. They are also good for multistrand conductor terminations.



Grub screw or pressure plate terminals are normally used for terminations in electrical equipment, e.g. switchgear, starters, breakers, contactors, etc.

Figure 135: Standard terminals for switchgear

8.3.1.5. Split-bolt connectors

Split-bolt connectors are used to join two or more cable ends together. They are also called line tap connectors. This is because they are often used to tap off a conductor (line) without switching off the circuit.

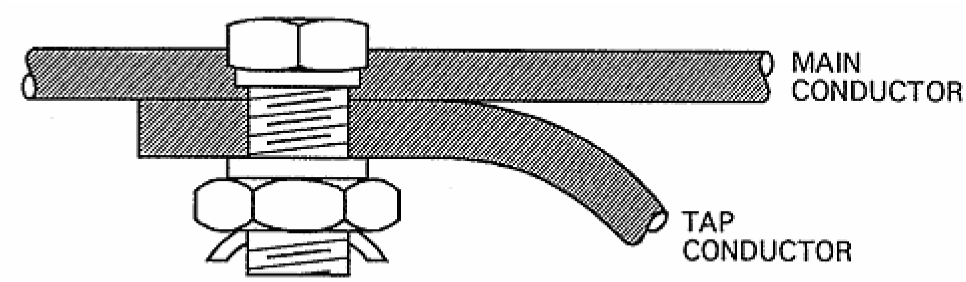


Figure 136: Split-bolt connector

8.3.2.

8.3.3. Crimped connections

Crimping is a quick and effective way of joining different types of termination devices to cable conductors.

Do not crimp a rigid core cable since it can be directly connected to the terminal block without any problems; it is even recommended never to use lugs on rigid cores!

But when dealing with stranded cores or even flexible wires it is a professional error not to use crimped terminations when the receiver's connectors are not adapted to the wires.

8.3.3.1. Crimped lugs

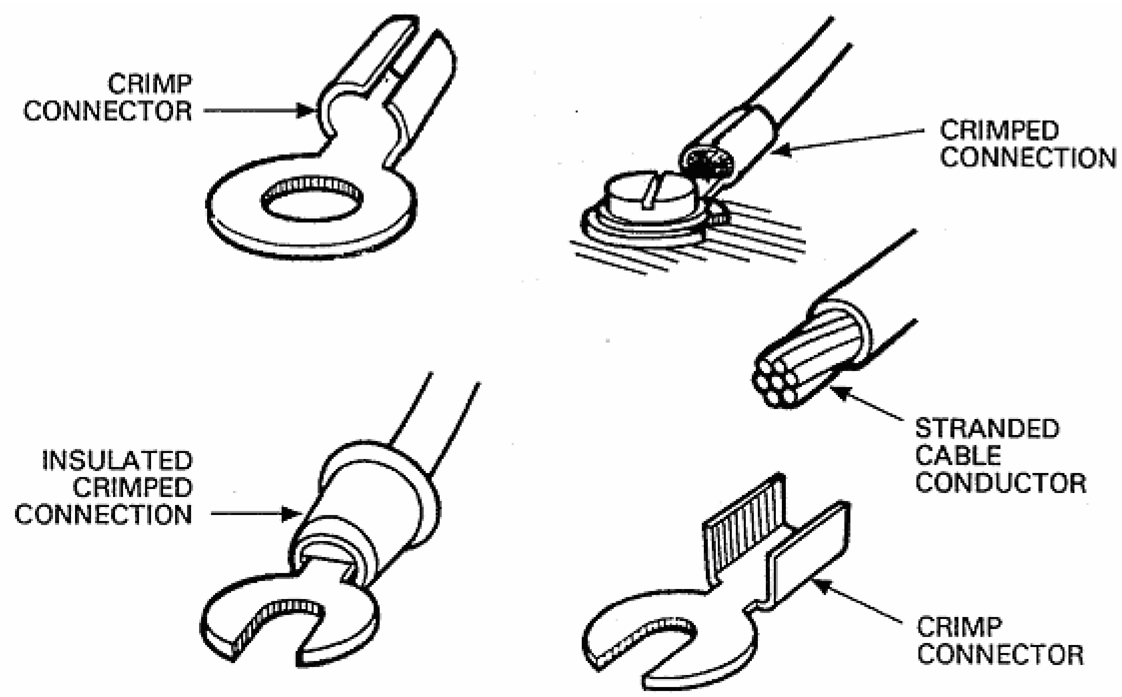


Figure 137: Types of crimped terminations (small wire sizes)

Crimping requires the use of a special tool (crimping tool) to apply enough pressure to form a good connection between the crimp connector and the conductor.

A correctly crimped connection has high mechanical strength and good electrical conductivity.

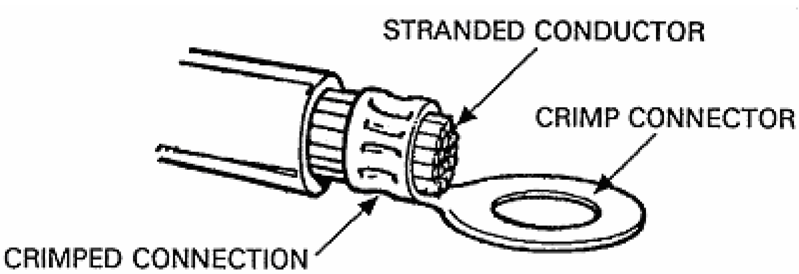


Figure 138: Crimped connection

Crimped connections are quicker to make and cheaper than soldered connections.

Crimped connections are often used for small cables and made by a hand-operated crimping tool.

But before crimping, you need to choose a lug or a sleeve and these depend on:

- Wire material: copper or aluminium – It can be also bimetal, crimped on aluminium cable and connected to a copper-based bolt/seat.
- Wire size: from 0.5 to 600 mm²
- Type of connection: pin, fork, blade, spade, ring, etc.

Figure 139: Table of crimp lugs / sleeves

With so many different sizes and types you are obviously not going to be able to use the same crimping method or the same crimping tool for all of them!

8.3.3.2. Crimping tools

Hand crimping tools often have jaws which can be changed to fit the different shapes and sizes of crimp connectors. You crimp the connection by squeezing the handles together.

The handles cannot be released until full pressure is applied to the connection (except for the “fastener” type crimping tool).

Then the ratchet releases the handles. This ensures that the correct pressure is applied to the crimp connection.

A power-operated crimping tool (hydraulic) is used for crimping the large conductors of high current cables.

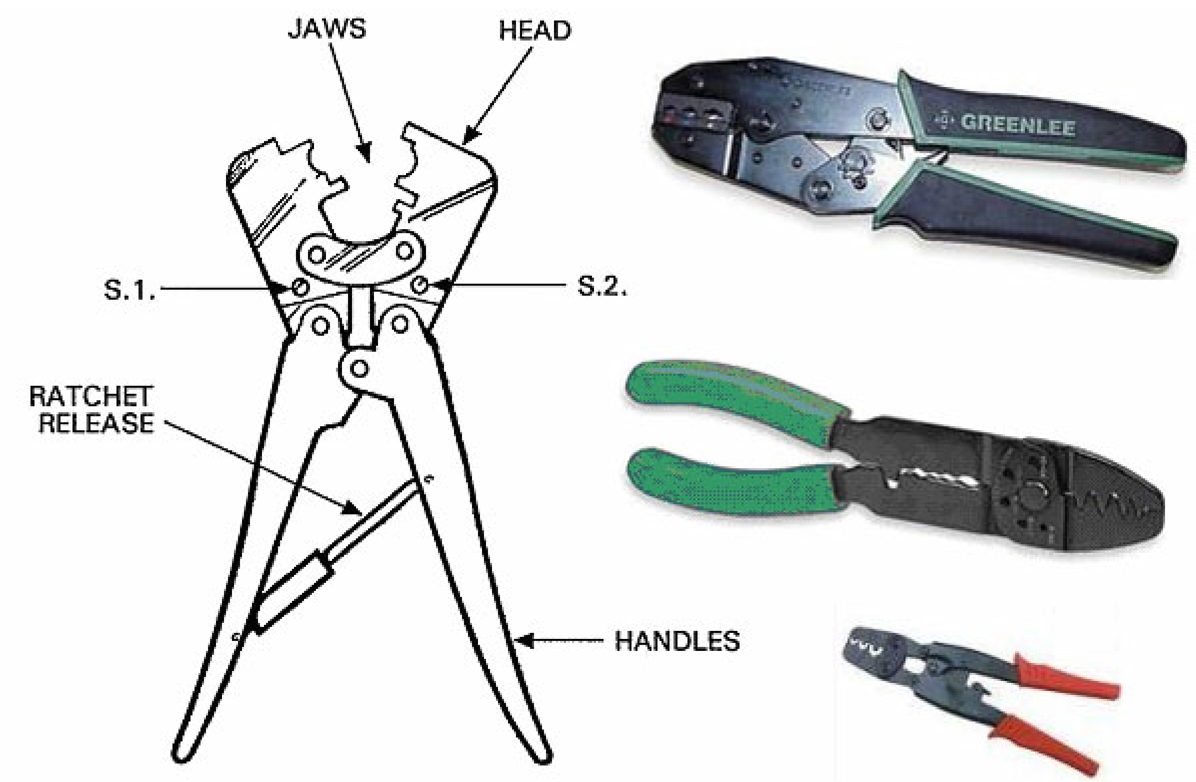


Figure 140: Hand-operated crimping tool

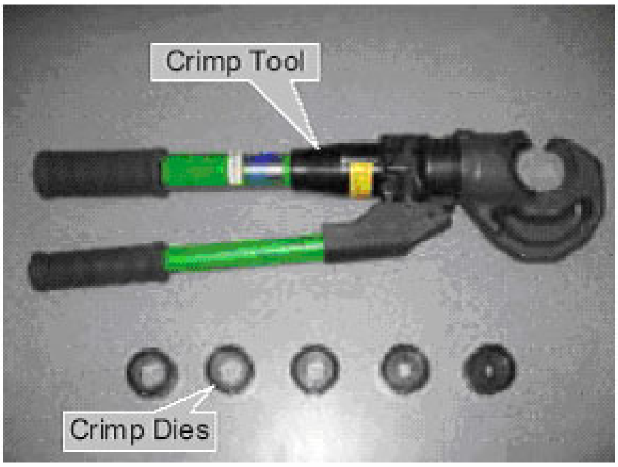


Figure 141: Hydraulic hand-operated crimping tool

With this type of tool for making a compression crimp, the correct die must be used (depends on lug/sleeve diameter).

The hydraulic crimping tool can be hand-operated, battery-operated or have a separate pump which can also be manually, pneumatically or electrically operated.

Figure 142: Hydraulically-operated crimping tool kit (hand-operated, battery, hand pump)

8.3.4. Making a crimped connection

1. Strip the insulation from the end of the stranded conductor.

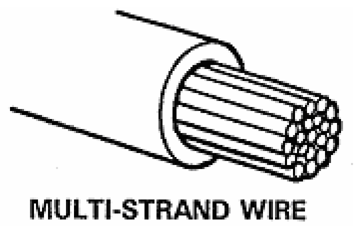


Figure 143: Remove the insulation from the wire

This systematically applies for stranded and flexible cable

2. Twist the strands together with pliers so they all fit into the body of the crimp connector.

3. Place the barrel of the crimp connector over the conductor

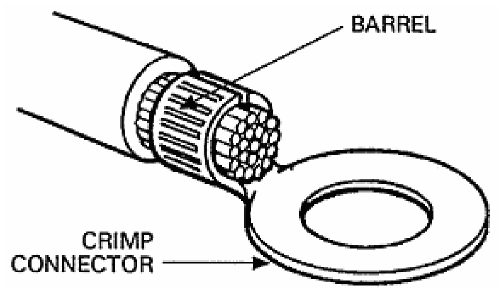


Figure 144: Place the device on the conductor

4. Place the barrel of the crimp connector in the crimping tool jaws.

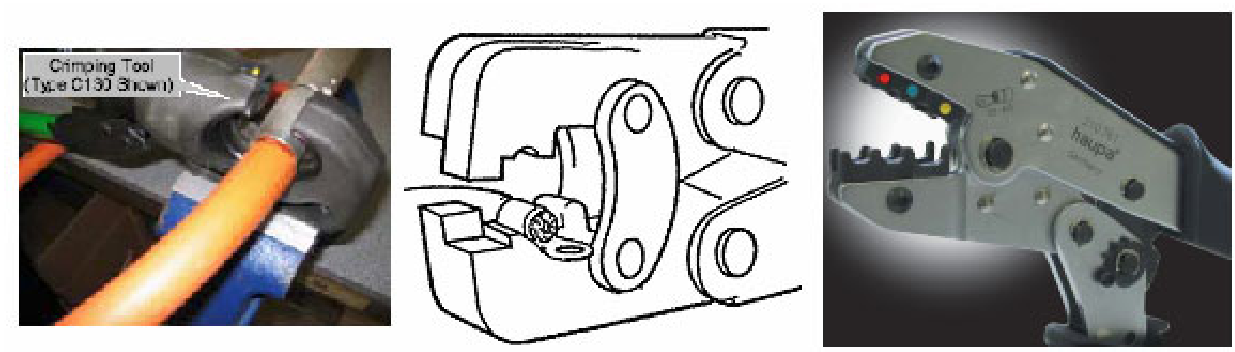


Figure 145: Place the connector in the crimping tool

5. Crimp the connection by squeezing the handles of the crimping tool, or start to pump

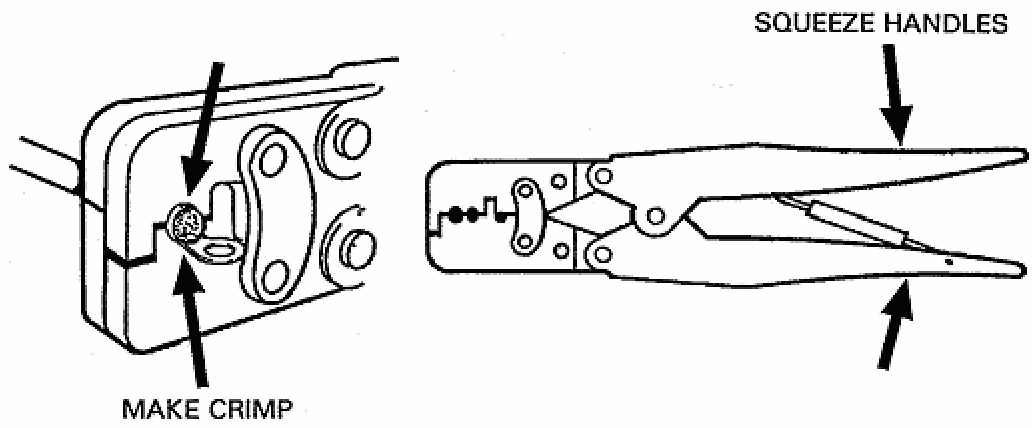
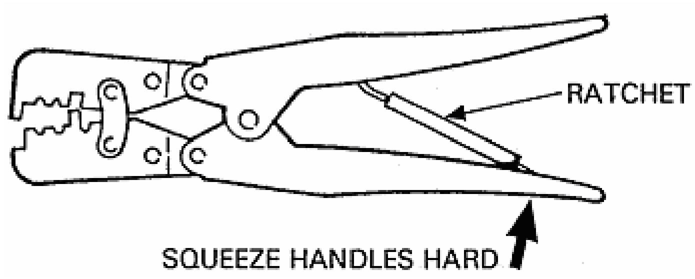


Figure 146: Making a crimp connection.

6. Squeeze the handles together until the ratchet releases them (the die is completely closed or the punch is at its maximum with the hydraulic unit).



Open the handles and remove the tool from the crimped connection.

Figure 147: Released Crimping Tool

7. Check that the connections are well-formed and perfectly made.

The wire has been stripped to the correct length corresponding to portion ‘B’.

The insulation is well inside its barrel.

The finished crimp is firmly secured.

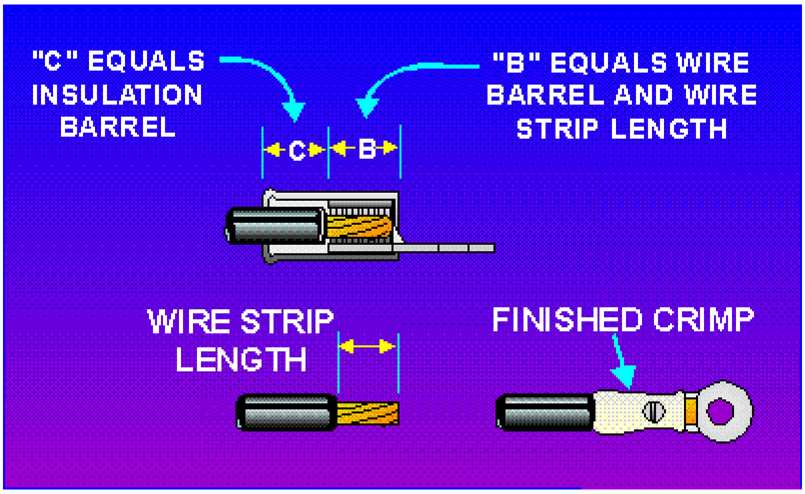


Figure 148: Summary of the crimping procedure

8.3.5. Use the correct crimping method

With a hand crimping tool for small lugs, it is a simple operation.

Once you have to use hydraulic equipment, it means that you have to connect cables of large cross-sectional areas and you must:

- Decide on the compression method and dies to be used.
  - Select the correct shape of die for the job.
  - Select the size of die for the diameter of the lug.
  - Ensure that the correct hydraulic pressure is used (check the manufacturer's recommendations).

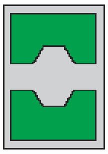
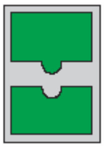
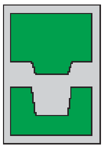
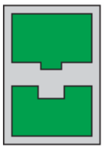
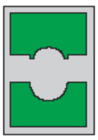
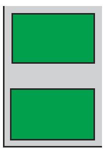
Diagram	Designation	Applications	Size
	***Hexagonal crimp***	Crimping ”normal design” Cu tubular cable lugs and connector tubular cable lugs for connections in switchgear.	6 to 1,000 mm^2
	***Mandrel shaped crimp***	Crimping ”normal design” Cu tubular cable lugs and connectors tubular cable lugs for connections in switchgear.	0.75 to 400 mm^2
	***Oval crimp***	Crimping double crimp cable lugs, C clamps, insulated tubular cable lugs and connectors, insulated pin cable lugs.	0.1 to 185 mm^2
	***Trapezoidal crimp***	Crimping sleeves with lug and twin sleeves lug.	0.14 to 185 mm^2
	***Square crimp***	Crimping sleeves with lug and twin sleeves lug.	0.14 to 6 mm^2
	***WM crimp***	Crimping ”standard” tube terminals.	10 to 400 mm^2
	***Rounding***	Crimping 90° and 120° sector wires	10 sm to 300 sm 35 se to 300 se
	***Cutting dies***		

Table 13: Choice of dies for a crimping tool

- Decide on the punching method to be used (bottom die)

Figure 149: Bottom-die crimping tool with separate hydraulic pump

- Slide the lug bed and punch the cover over a certain diameter only
- Change the bed and punch according to the lug diameter if your tool can handle it.
- Check the manufacturer's recommendations for the number of punches on the selected lug.

- Position the lug correctly

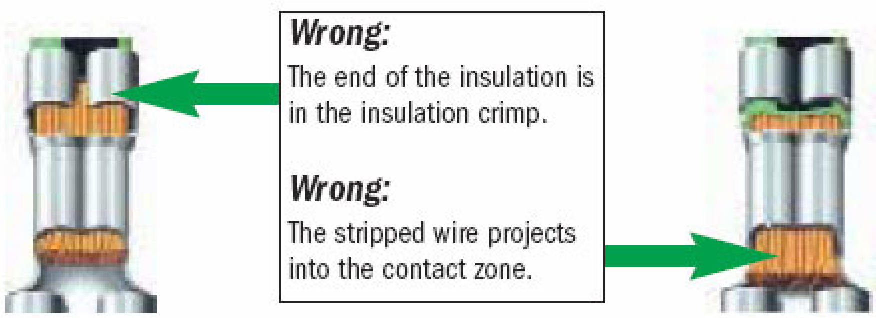


Figure 150: Wrong positions of wire on lugs

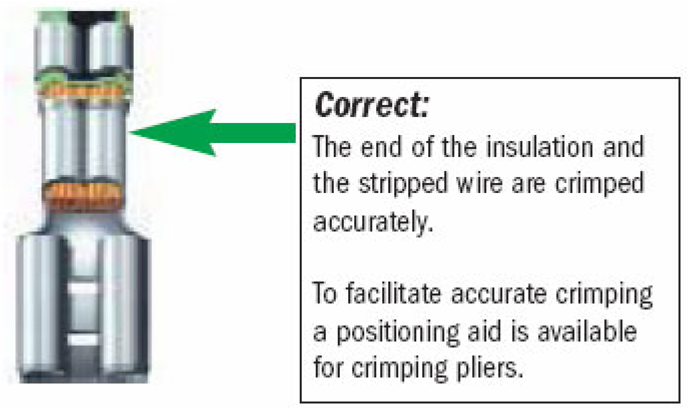


Figure 151: Correct positions of wire on lugs

This lug position is (of course) valid for all types of lugs and sleeves.

With a preinsulated compression lug, do not forget to insert the wire's insulation into the part of the lug designed for this purpose.

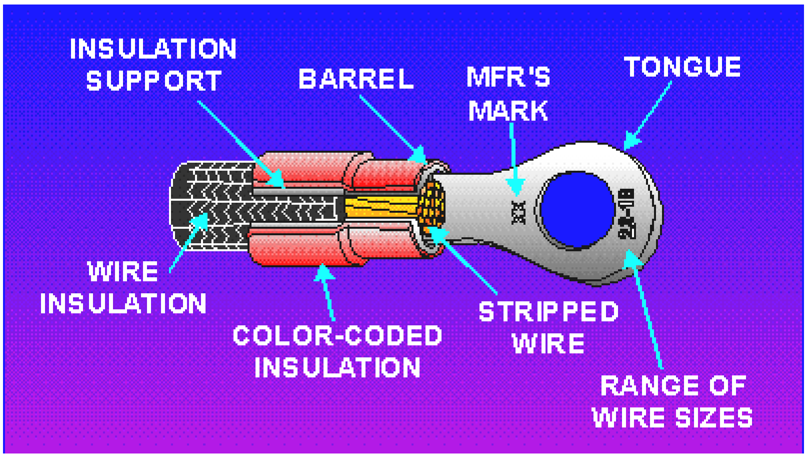


Figure 152: Preinsulated straight copper terminal lug.

- Crimp the cable lug or connector using the correct tool, take account of the crimping direction (when several crimps are required).

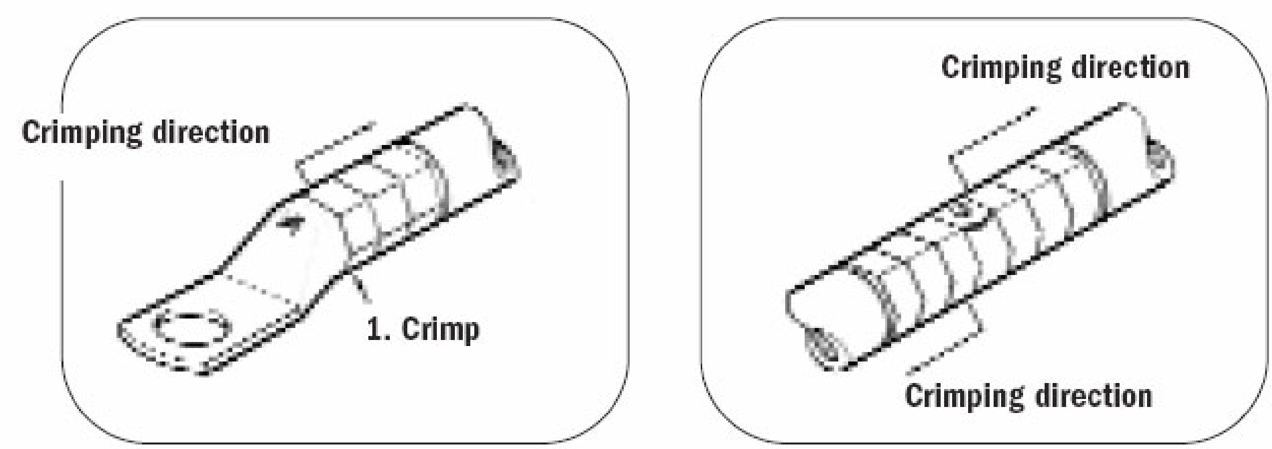


Figure 153: Crimp in correct direction

- Discard any “failed” crimps

Figure 154: Crimping problems…

This kind of problem (lug cracking) can occur either due to a material failure (manufacturer's responsibility) or to a wrongly used crimping tool (wrong die, excessive pressure).

- Make at least a double crimp (large lugs)

  The recommended method is to double crimp although single crimps may be suitable for smaller cables.

  The crimps should be at 90° to each other and positioned centrally within the contact zone to be crimped, as shown in the figure (in this case: hexagonal die).

If a single crimp is used, the crimp should be positioned centrally within the 35 mm zone shown in the figure.

Crimp in the order shown to ensure a satisfactory crimp is obtained. Consult the workshop manual/manufacturer's manual if any additional information or advice is required.

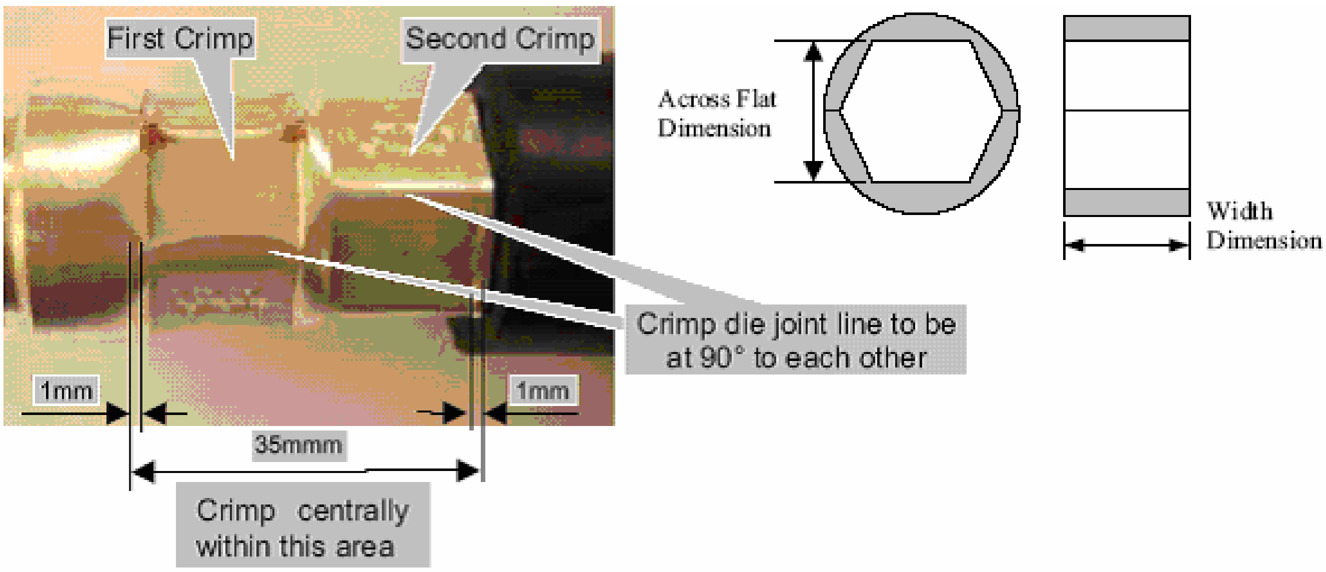


Figure 155: Double crimp recommendation for standard die dimensions

9. FIGURES

10. TABLES