



# CNC

## STD 1

### APPENDICES TO THE USER'S MANUAL FOR S&h CONTROLLERS

- Goya
- Picasso2000
- Rubens

*VERSION APPENDIX :* 1.2

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**APPENDIX VERSION: 1.1**

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## NOTES FOR USING THIS DOCUMENTATION

This document applies to controllers manufactured by S&h.

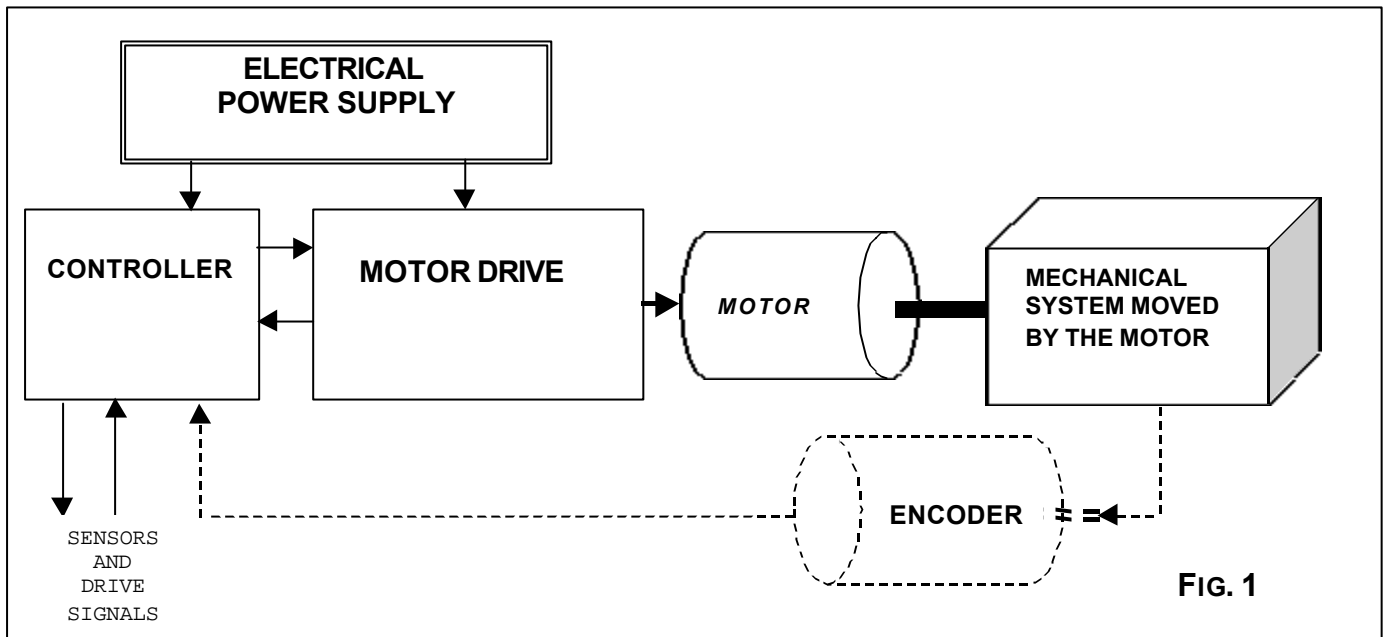


Figure 1 shows the generic principles of an application of a numerical controller to control movement. It shows clearly the position and function of the object of this manual - the controller. For further clarification, all the elements shown in this diagram are described below.

- **Electrical Power Supply:** all those parts of the system whose function is to provide the correct voltages and current supplies to the controller (and other constituent parts of the system). It usually contains a transformer and associated protection devices that must be installed by the user. S&h controllers require a D.C. power supply, which means that the *power supply* must include the rectifier and smoothing circuit.
- **Controller:** the part of the electronic system that generates the signals, on the base of which the mechanical parts must be moved. These signals are generated according to the indications given by the operator or by the program being executed and comparing these with the actual positions of the mechanical organs and taking into account the responses of the devices that form part of the system.
- **Motor Drive:** the part of the electronics of a system for controlling mechanical movement that receives/transmits analogue/digital commands from the external controller and drives the motors so that they perform the movements required by the controller itself.
- **Motor:** converter of electrical energy into mechanical energy that determines the movement of the mechanical organs.
- **Mechanical system moved by the motor:** the assembly of fixed and moving mechanical parts through which the movement takes place.
- **Encoder:** electronic and mechanical device moved by the motor or other moving parts of the system and which supplies the controller with information regarding the relative displacement of the mechanical parts. If this device is not fitted, the system can be moved in “open loop” using a stepper motor whose displacement, due to the way with which its movement is generated, is known with certainty.

The products described in this manual (see the list on page 4) bear the CE mark and conform to the following directives:

- Electromagnetic compatibility (89/336/EEC and subsequent revisions)

Remember that, as affirmed in all directives, the conformity only applies when the product is used for the function for which it was designed, following the manufacturer's instructions. Therefore all instructions concerning the use, precautions, installation methods and limitations must be respected by the user for the conformity to be valid. In this regard, the following chapters are particularly important even if all the instructions described in the manual for installation and use (not just this appendix) must be studied carefully and interpreted to obtain the necessary information for the correct use of the product itself.

The conformity declarations of the products concerned (see the list on page 4) are held by S&h (as manufacturer domiciled in a member state of the EC) together with all the technical documentation for the manufacture and these are available for inspection by the competent authorities.

The purpose of this manual, together with the instruction manual, is to provide project designers and personnel concerned with the equipment's safety with information on the characteristics, function, methods and limits of use in control applications of the series listed on page 4. The knowledge of this information is essential for the correct design of the machines, equipment or systems in which the controllers are used. It is therefore strongly advised that no operation is performed on the controller before having studied all the information contained in this appendix and in the manual of installation and use of the controller itself. Should any part of the manual be unclear or lacking regarding a specific application situation, please contact S&h who, on the basis of their experience, can provide further explanation where necessary. Remember that improper use or a malfunction can cause injury to people and damage to property if the proper precautions are not taken or safety devices are not fitted.

Please remember also that the products may be used in a wide range of applications and installed in vastly different environmental conditions. For this reason, this manual can only indicate general rules and limits. It cannot be expected to take all possible applications into consideration. S&h is always available for further information, if required.

The terms «user» and/or «customer» used in this manual always refer to a professional installer as defined in the section: *“Limits of Use, Risks and Precautions”*

The manual reflects the current state of the art for the commercialisation of the products and cannot be considered adequate for subsequent enhancements that may be introduced as a result of new knowledge and experience. S&h reserves the right to update any products and/or manual without notice and without obligation to update previously supplied products and/or manuals.

## **LIMITS OF USE, RISKS AND PRECAUTIONS**

S&h controllers, including their options and/or accessories, are built for controlling the movement of the axes of a machine (through the control of the relative motor drives) and for handling the I/O of the sensors and actuators fitted on the same machine. The use of these products for different applications is forbidden.

Except where explicitly mentioned in the Users' Manual, both the motion controllers and the accessories that may be present are fundamental elements and are not provided with their own protection (Grade of Protection IP00). It is therefore important to ensure that they are fully protected for the environment in which they will be used and are not accessible for contact by persons or objects when they are powered up. In other words, they must be installed in electrical cabinets or protective containers that satisfy the requirements of the standards laid down for the specific application so that they are not accessible when powered.

In the event of malfunction due to accidental causes or wiring errors, the boards that make up the motion controller, as for all electric/electronic components, can, in the extreme case, give rise to the formation of an electric arc. For this reason, it is essential that they are mounted in an environment where inflammable products are never present. Furthermore, it is recommended that all components mounted in the same cabinet as the motor drives are constructed of self-extinguishing material.

The S&h controllers are components that have not direct function themselves but are designed to be integrated in more complex equipment or machines by a user that must be a professional operator. The direct use of these materials by the end user is not allowed. The professional operator who uses these products must be sufficiently qualified both in the field of electrical and electronic equipment in general and specifically in the application of motion controllers and the components associated with them (motor drives, motors, actuators, sensors....). The designer of the whole system in which this component is used is responsible to ensure that all necessary precautions are taken for the safety and reliability of the system. Only he can be aware of all the technical, economic, legal and standards implications for the particular application in which it is used. It should be remembered that installer of the equipment to provide the certification of the conformity of the whole system to any European directives to which it may be subject. For matters concerning the directive 89/336/CEE, see the suggestions in the chapter concerned.

The terminals that carry the low voltage analogue and discrete signals (+5V,  $\pm 10V$ ) of the I/O, in particular those that connect the motor drive are not galvanically separated in the controller. Therefore take this into account when considering the safety of the machine and examine the possibility of a dangerous voltage reaching these terminals and if necessary, galvanically separate these signals externally.



The use of the controller for functions related to safety is forbidden (EN 60604-1). Suitable independent safety systems must be installed if, for the particular application conditions, a malfunction or incorrect controller function could generate dangerous conditions.

## **INSTALLATION MODE AND THE ENVIRONMENT**

Unless specifically mentioned in the users' manual, all the products (and associated accessories) mentioned in this manual have the following common features:

- Unclassified (EN60529) grade of protection; which means that it is the users' responsibility to provide a container of adequate protection that conforms to any standards required for specific applications.
- Connection to a network: must not be direct; a suitable transformer must be used to provide the correct voltage and the galvanic separation from the network itself (the transformer must have the screen between the primary and the secondary windings connected to ground). For the correct supply of power to the controller it will be necessary to provide suitable rectifiers and filters.
- Grade of contamination: installation is allowed in a local environment with grade of contamination 2 (IEC-664-1 chap. 2.5). This means that if the environment in which the machine is operating and of which it forms part does not satisfy this requirement, an adequate system of conditioning must be provided for the container. In any event, installation is forbidden in an environment where inflammable, corrosive or electrically conductive gases, vapours or powders may be present. It is also forbidden to install the equipment close to other easily inflammable components or materials.
- Ventilation: the controller does not require forced ventilation, provided that adequate circulation of air is permitted around it. If excess heating is observed and judged a possible source of problems, a suitable fan must be fitted above or below the controller itself.
- Power supply: see the users' manual.
- The ambient temperature during operation must in all cases stay within the range between +5°C and +45°C.
- The storage temperature must be in the range between -10°C and +70°C
- Maximum altitude for operation: 2000m

## **RECOMMENDATIONS FOR CONFORMING TO THE 89/336/EEC DIRECTIVE**

### **Electromagnetic Interference and Immunity:**

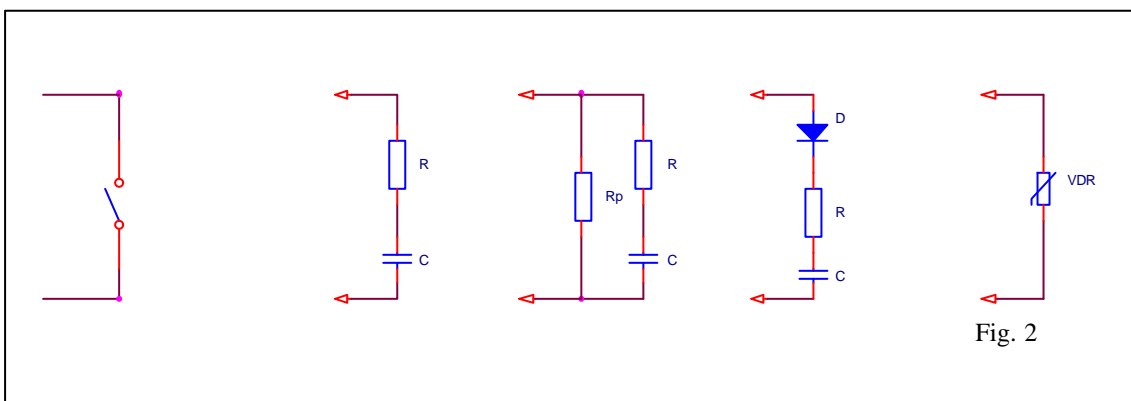
It should be remembered that the system that comprises the controller, motor drive, transformer, power supply, motor and associated wiring is, by its nature, a source of electromagnetic interference that must be adequately screened when the plant containing it is installed. The professional assembler has the responsibility of ensuring that the finished installation meets the requirements of the mentioned directive and any other specific standards for the application. Tests performed by S&h on specific systems have demonstrated that the most effective measures to be taken, during the installation phase, to reduce the airborne and wireborne interference generated by the system are the following:

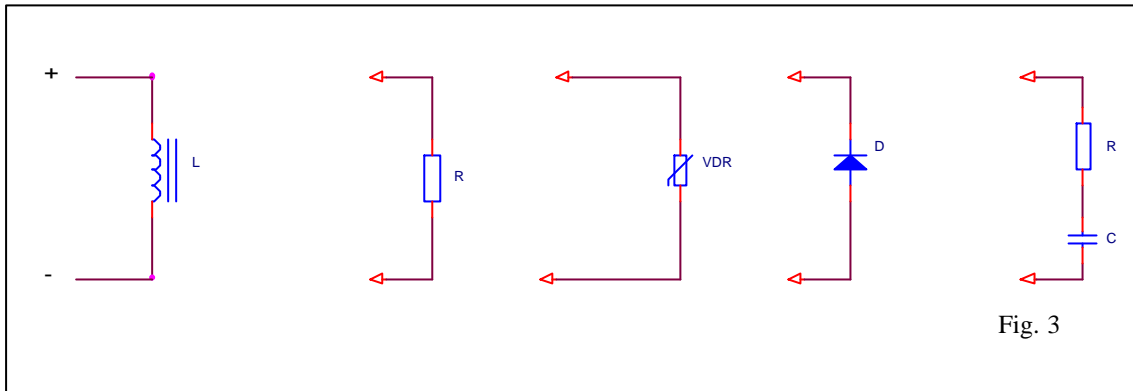
- **Positioning of the controller:** The controller and associated power supply (transformer) must be mounted in a single electrical cabinet that is hermetically sealed against electromagnetic fields. Because of the frequencies involved, the cabinet can be considered hermetic if it has electrically conducting sides and no aperture of area greater than 50mm<sup>2</sup>
- **Wiring:** All the cables used for connecting the controller must be screened. The connection of the mesh screen must be very short (long connections annul the effect of the screen). It is recommended that the screen is connected directly to the casing of the connector. The connector should have a metallic casing (see the specific recommendations in the manual for installation and use).
- **Serial interface connection:** Use a screened cable, with the screen connected at both ends. The RS232 type of link may only be used for distances up to 10m. For longer cable runs, or in environments with a lot of electrical noise, use RS485 or RS422, use a screened twisted pair cable.
- **Ground connection:** Two separate ground bars with independent ground connections should be used. One of these is used for the digital control section and the other for the power section. The controller must be connected to the ground connection point of the digital section of the electrical cabinet, using a wire of cross-section  $\geq 4\text{mm}^2$  connected to the ground connection of the controller itself. The ground connections to all the components of the system should be as short as possible.
- **Power supply:** Use a transformer, with metallic screen between the primary and secondary windings connected to ground, to supply the controller. It is not advisable to use a secondary tap from a transformer that supplies the power sections (i.e. motor drives).
- **Insert a line filter on the 220Vac or 380Vac input to the electrical cabinet.** It is recommended that such a filter is used, even if it is not required by the controller itself, as it will reduce the wireborne interference that can be radiated from the cables from the machine or the whole plant. Its position in the plant is particularly important. It should be at a point, upstream of which, there is no possibility of electromagnetic coupling with elements of the plant that could develop electrical noise (avoid coupling with the input

wiring and those exiting through the filter). Take care that the filter is adequately sized for the application so that it can fulfil its function.

The aspect of immunity for the discrete input signals to the controller from external noise is covered by the following recommendations that summarise the precautions that should be taken:

- Always use screened cables
- Whenever that cable length exceeds 5-6m, use buffered signals rather than the direct open collector signals.
- Physically separate the paths of the power cables from those of the control signals. They should not cross, rest on or twist around them. If it is impossible to avoid them crossing, do this at an angle of 90°. Wherever possible, place the power cables in conductive metal cable trays connected to ground.
- Noise suppression: The controllers are fitted with an anti-interference system. Nevertheless, the interference from connected cables can affect the reliability of the controller. Arc suppression should be employed wherever necessary, and inductive peaks from switching should be smoothed. Furthermore it is important that:
  - The anti-interference device is located as close to the source of the problem as possible
  - The anti-interference device is fixed well mechanically and will not break off due to vibrations.
  - Use only components that are marked as anti-interference devices (see also Figs. 2 and 3).
  - Carefully check the compatibility of the logic levels in the interface between the controller and devices attached to it (motor drives, encoder, etc.).





- Low voltage (directives 73/23/EEC and 93/68/EEC):  
 Since the motion controllers mentioned in this manual are components that work at very low voltage, where both the supply voltage and those generated inside the equipment are less than 50Vac/75Vdc, they are automatically considered excluded from the above-mentioned EEC directives.

The adoption and correct implementation of these recommendations constitute an essential starting point for creating a system that meets the requirements of the above directives. The actual conformity of the system to these requirements must be tested when the installation is complete as the effectiveness of the provisions suggested depends on the layout of the machine and their correct implementation. Tests that we have made simulating typical plants and following the above recommendations show that it is possible to build plants that are within the limits imposed by the standards.

# **CNC – APPENDIX B: S&h RECOMMENDATIONS FOR MINIMISING ELECTROMAGNETIC INTERFERENCE**

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## **PURPOSE OF THE APPENDIX**

As the conditions imposed by the various EMC standards become more stringent, the collaboration between the manufacturers and the installers of electronic equipment becomes more necessary. Now that the aspect of electromagnetic compatibility for electrical cabinets assumes an importance that is become almost the same as that of safety, and often to the disadvantage of that of practicality. This appendix is aimed at technical personnel responsible for the installation of S&h control products, is intended to be a guide for resolving the problems associated with electromagnetic noise and a recommendation of a way of working in an environment in which electromagnetic compatibility is of primary importance

## **COUPLING MECHANISMS BETWEEN SOURCES OF NOISE**

A noise signal or interference is generated by a source (cable or device). It is propagated along conductors or as a disturbance of the electrical and/or magnetic field through insulators and acts on a receiver, for example, a signal wire, the case or internal circuitry of a device or of a particularly sensitive electronic component. Such a receiver is called the *circuit victim*.

If the conditions are favourable for a coupling between the source of the noise and a circuit victim, the noise will be propagated in one or both of the following ways:

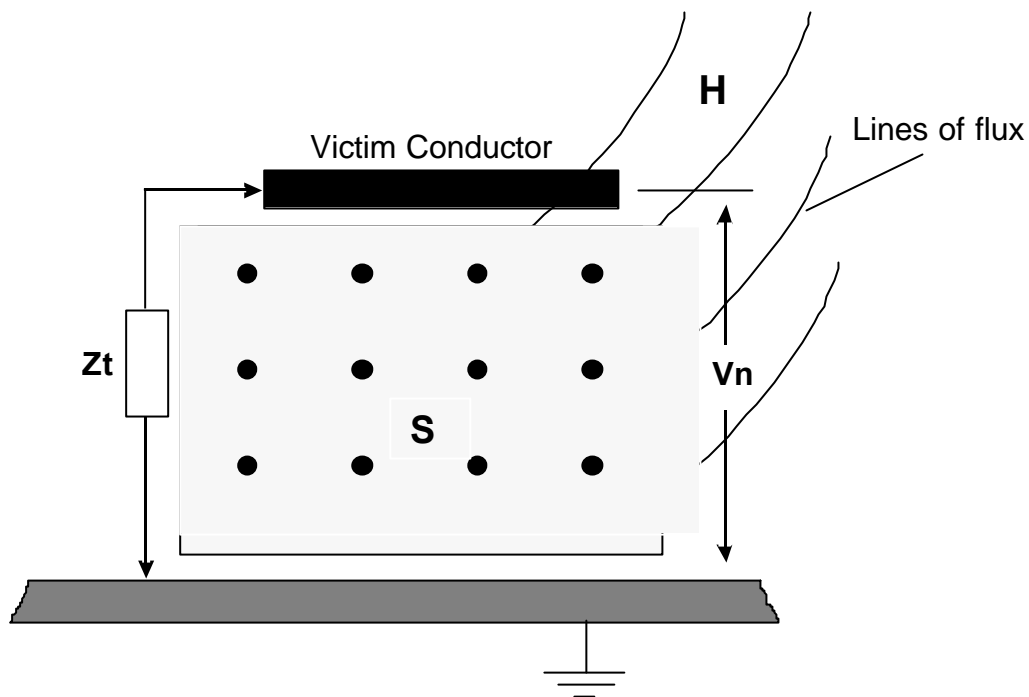
- Conduction along the wire.
- Radiation through the air.

In the first case, it is called conductive noise, and the second is called radiated noise in which the circuit victim behaves like receiving aerial.

There can be various types of coupling between the source of the noise and the circuit victim:

- Inductive coupling
- Capacitive coupling
- Common impedance coupling
- Electromagnetic radiation coupling.

## INDUCTIVE COUPLING



$Z_t$  : impedance towards ground

$V_n$  : voltage induced by inductive coupling

$H$  : magnetic field of the noise

$S$  : area of exposure

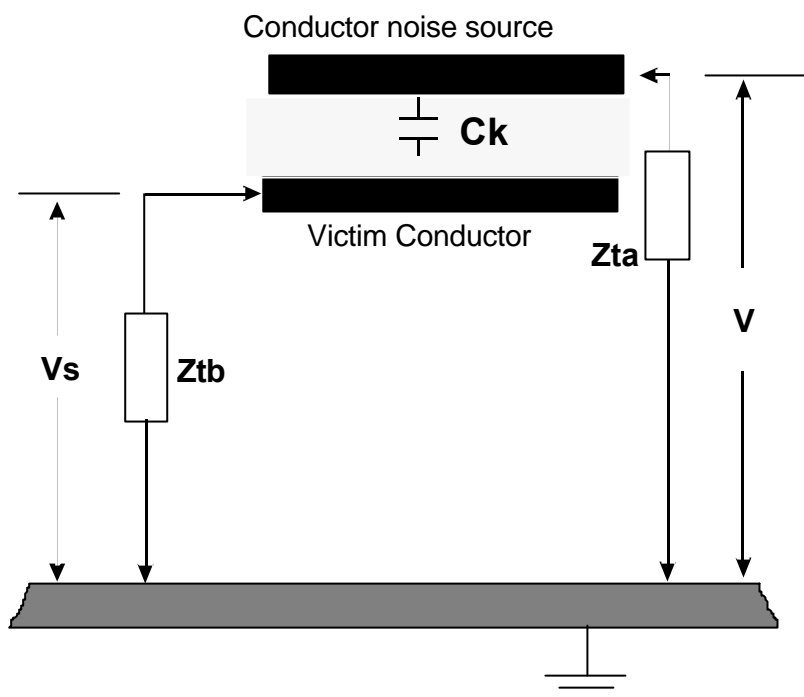
**Fig1: Inductive Coupling**

The victim conductor is interested in a certain part of the variation of magnetic flux generated by a current loop. The result is an induced noise voltage  $V$ .

The interference voltage will be greater when:

- The area  $S$  is larger
- The higher the frequency of switching of the source of the disturbance of the magnetic field

## CAPACITIVE COUPLING



$Z_{ta}$  : impedance towards ground of the conductor that generates the noise

$Z_{tb}$  : impedance towards ground of the victim conductor

$C_k$  : capacitance of the coupling

$V$  : Voltage on the conductor that generates the noise

$V_n$  : voltage of the resultant signal from capacitive coupling

**Fig. 2: Capacitive Coupling**

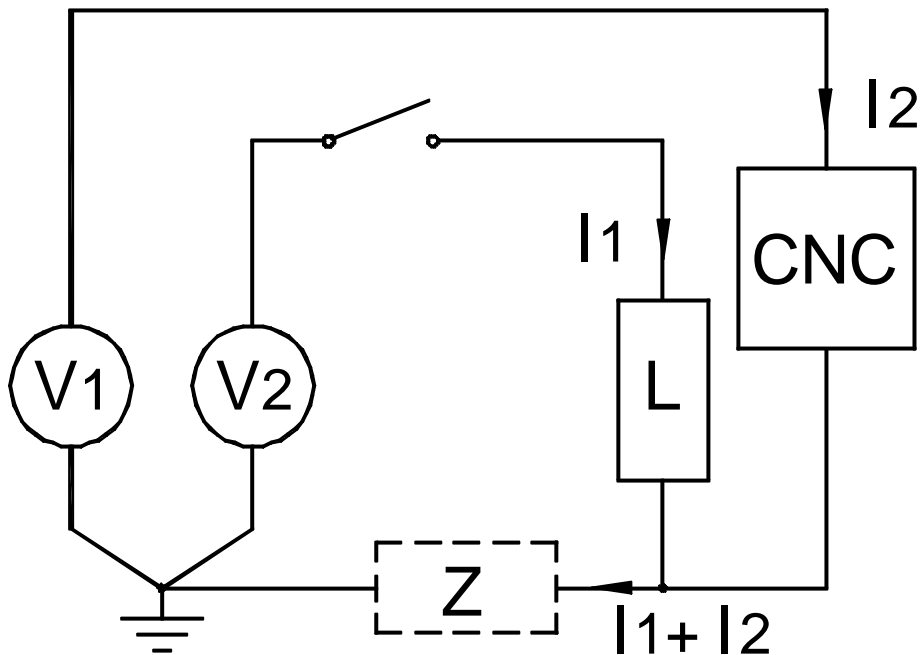
Capacitive coupling occurs when two conductors at a different voltage run parallel for a certain distance. The effect is a load sharing between the two conductors that generates a noise voltage on top of the wanted signal.

The voltage produced by the interference will be greater:

- The greater the capacitance of coupling which is inversely proportional to the distance between the conductors and directly proportional to the length along which they remain parallel.
- The faster the frequency of switching of the source conductor.



### COMMON IMPEDANCE COUPLING



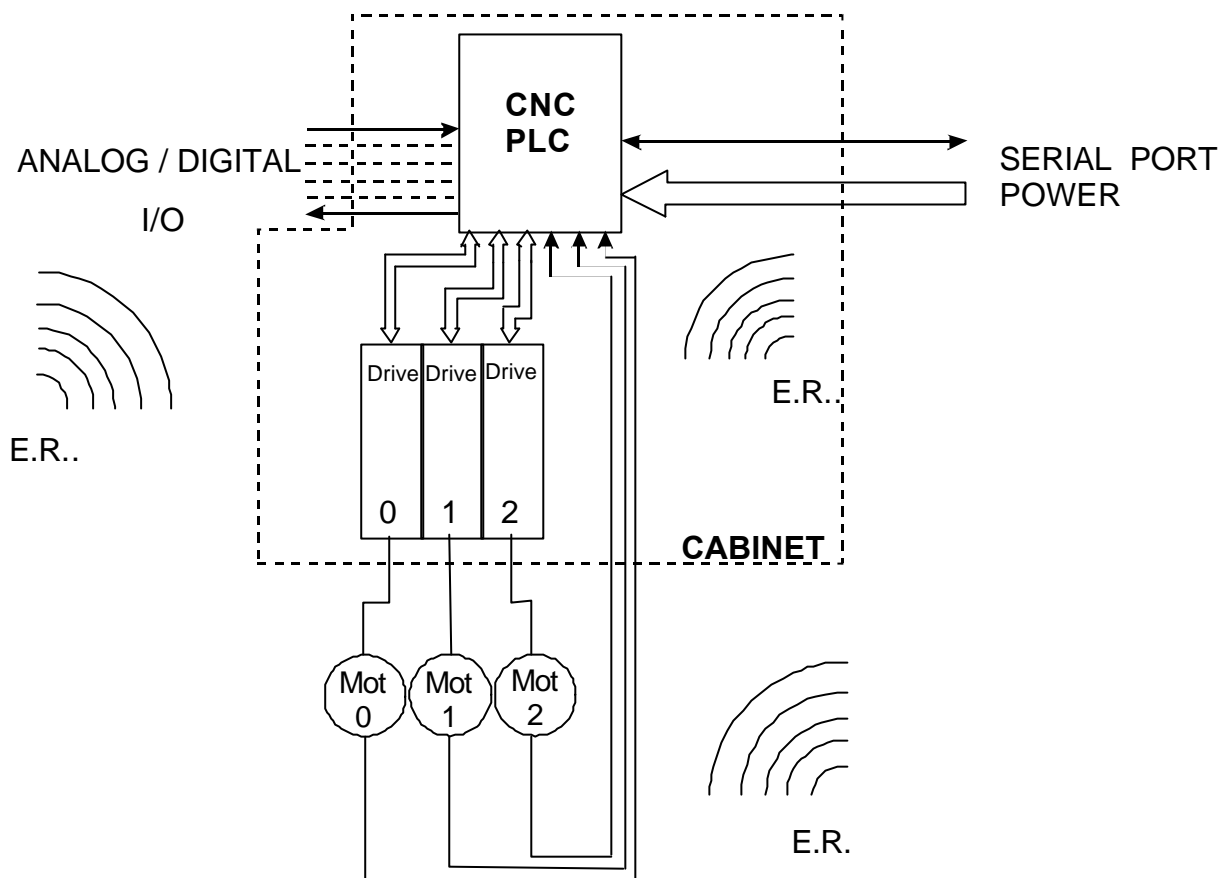
**Fig.3: Common impedance coupling**

Common impedance coupling occurs when two circuits have a common tract with impedance  $Z$ . The effect is a noise voltage in both circuits, where the reference voltage of one is altered by the current in the other.

The interference voltage will be greater when:

- the greater is the inductance and the resistance in the common tract, both are proportional to the length of that tract.
- the higher the frequency of switching of the signals in the two circuits.

### ELECTROMAGNETIC RADIATION COUPLING



E.R. : Electromagnetic radiation

**Fig.4: Coupling through electromagnetic radiation**

Radio telephones, radio and television transmitters, high frequency devices for industrial applications produce electromagnetic waves that propagate and the energy is transformed into noise voltage or current in the various circuits of the victim devices that are inside or outside, that act like a receiving aerial.

The coupling depends on:

- the relative positions of the source and victim devices
- the screening and its efficiency.

## **WIRING**

Particular care should be taken when positioning the equipment and cables inside and outside the cabinet in which the controller is mounted in order to minimise capacitive and inductive coupling

### **WIRING INSIDE THE CABINET**

The wires that are connected to the controller are divided into three categories according to the degree of emission and susceptibility to noise:

- 1<sup>st</sup> category:
  - power cables
  - cables for power I/O signals (solenoid valves, power contactors)
- 2<sup>nd</sup> category:
  - cables for signals used for serial or parallel communications
  - cables for low power I/O signals (photoelectric signals, proximity switches, LED's etc.)
  - cables for encoder signals
- 3<sup>rd</sup> category:
  - cables for low level analogue signals (thermocouples, load cells).

As the category level increases, the voltage levels in play go down. These signals consequently have a greater susceptibility to noise. Later, it is shown how to lay the cables according to the category to which they belong.

Distance the cables for signals of the 1<sup>st</sup> category as far away as possible from the other signal cables, or to be more precise, keep them at a minimum distance of:

- 30 cm from the analogue signal wiring
- 10 cm from wiring of the 2<sup>nd</sup> category

When cable must cross, they must do so at an angle as close to a right angle as possible, in order to avoid inductive coupling and minimise capacitive coupling..

Laying the outward signal cable and its return together further reduces inductive coupling. They should also be twisted around each other (twisted pair).

Avoid laying cables of different voltage levels in parallel over long distances (e.g. 24Vdc cables with 220Vac cables).

Separate cables that carry dc voltage with those of ac voltage using dividers (see Fig.6).

Power the controller, uncoupling it from the three-phase supply lines through a transformer, especially for installations that are close to generators of noise, use an isolating transformer to power both the controller and the input devices. If this is not possible, use a phase voltage that is different to that used for the large inductive loads of the plant, e.g. motors, solenoid valves etc..

The layout of the components inside the cabinet is fundamentally important in order to avoid the effects of radiation and conduction interference. Subdivision, according to the power employed by the components, helps reduce the coupling because signals having high voltage levels will be automatically kept apart from those of low level and high susceptibility

The following figure indicates with what criteria to use when laying out the components and wiring inside the cabinet.

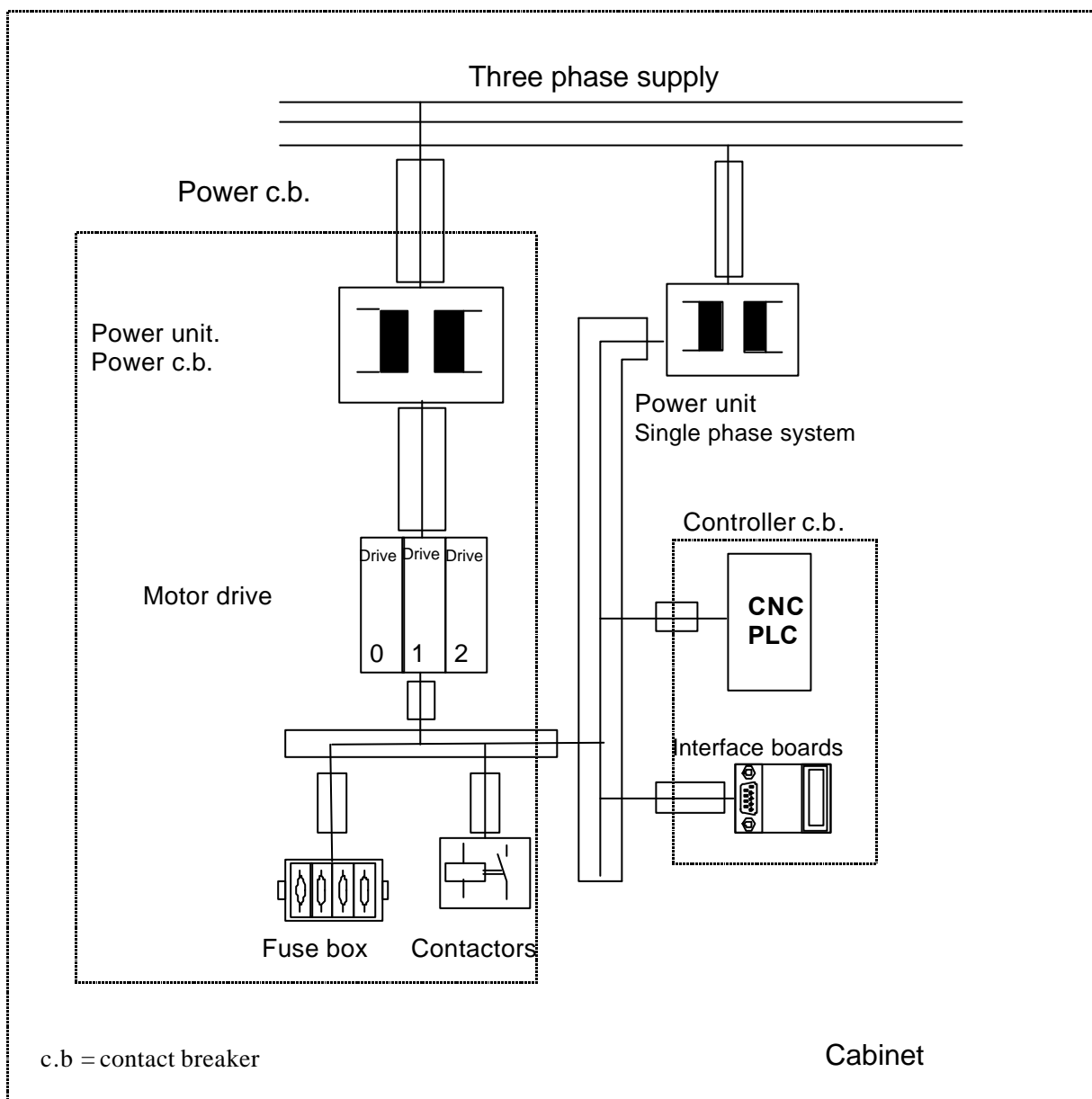


Fig. 5: Layout of components and cables inside the cabinet

### **CABLES OUTSIDE THE CABINET**

The same criteria applied previously are valid:

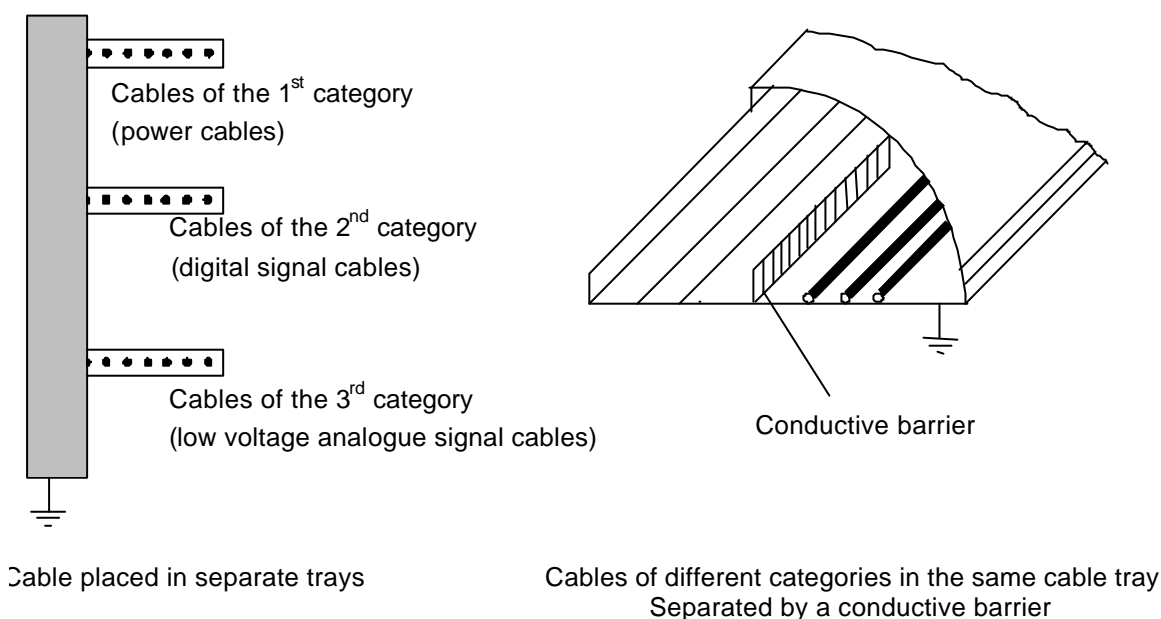
Separate the power cables from those of low voltage if possible, laying them in metallic cable trays connected to ground (see Fig.6).

It is advisable to lay the analogue signal cables in separate trays.

It is also better to separate the ground conductor from the three phase power lines, avoiding using the same cable trays. If this is not possible, separate the two cable types with a barrier of conductive plates as shown in Fig.6.

### **METHOD OF LAYING THE CABLE RUNS**

Place the cable trays in separate locations according to the category they belong to:



**Fig.6: Layout of the cable trays**

The trays must be closed and made of metal material. It is essential that these are connected to ground to ensure adequate screening efficiency from inductively coupled, common impedance coupled and electromagnetic radiation noise

The vicinity of the return power cable, in the power cable tray, minimises the interference to the magnetic field it creates because the current is equal and opposite in both directions and the fields they produce cancel each other.

In any case, it is better to minimise the area by the circuits that emit more (power circuits) or those that are particularly susceptible (analogue signal circuits), e.g. twisting the power cables (and the signal cables) with their return wire in order to reduce the area covered.

## GROUND CONNECTION

The relevance of the ground connection importance in the protection against noise (functional ground connection) is discussed in this paragraph.

S&h controllers are provided with holes on the rack for screw fixing to the cabinet door. Often, these mechanical fixings, unless particular care is taken, cannot be considered good electrical contacts as the cabinet is a structure of various part connected together. The joints between the various parts make a higher resistance to an equivalent solid conductor because the parts do not fit perfectly, due to difference in materials, because of oxidation etc. For this reason, it is advised that one of these holes is used for a functional ground connection using an auxiliary cable as shown in fig.7.

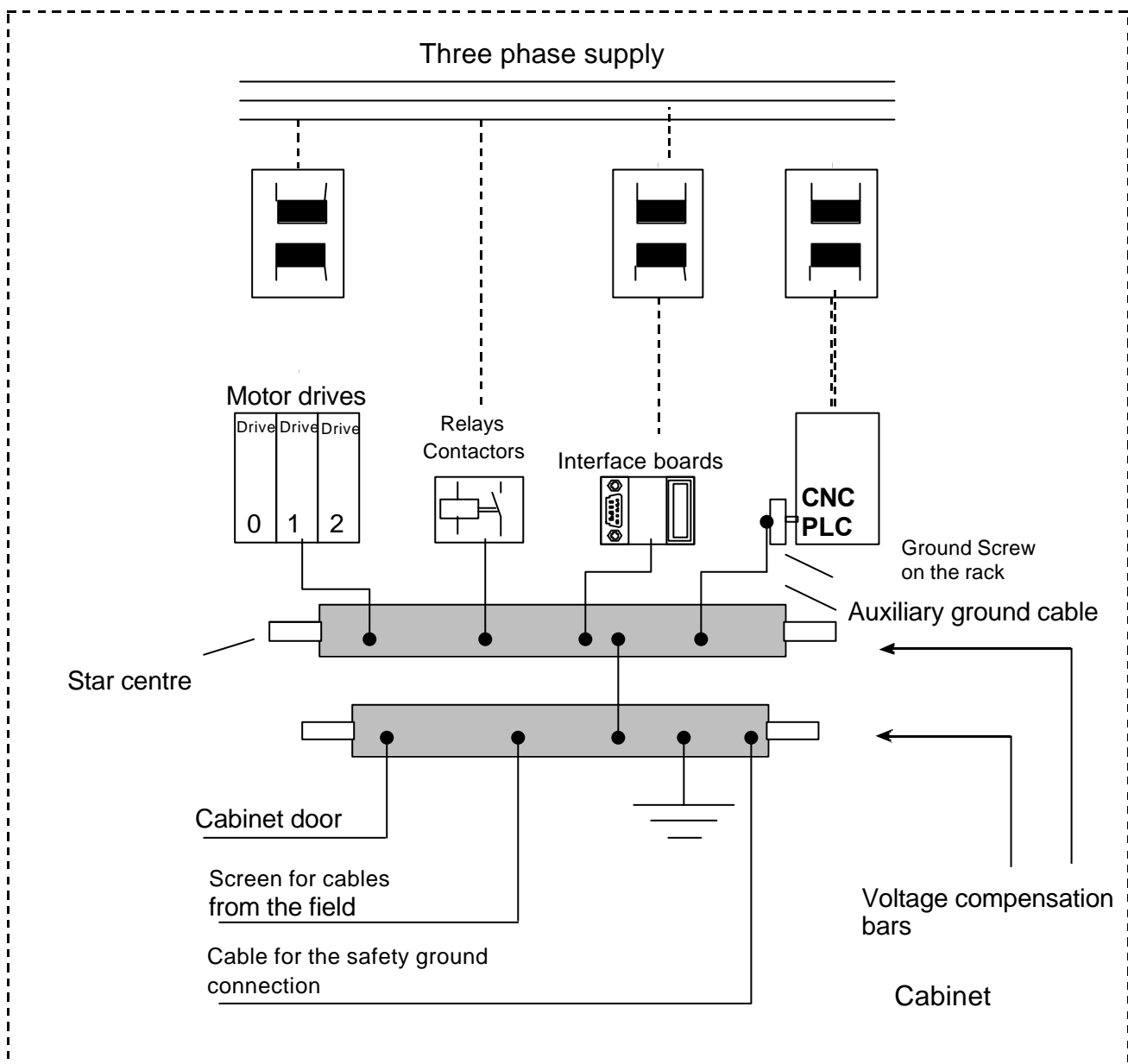


Fig.7: Layout for the ground connections

In this figure, it is recommended that the cable for the auxiliary ground connection is connected to star centre of the ground network for the cabinet, that must be made using a ground connection strips (platelets) of large contact area (which means low inductance and low resistance) or with cable of section  $\geq 6 \text{ mm}^2$ .

It is better if the connections to the compensation bar are short and with a large surface area of contact.

The compensation bar to which the screens of the field cables are connected (see Fig.8) should be connected to ground with conductors of cross section  $\geq 10 \text{ mm}^2$ .

If the mechanical joints are to be used as electrical contacts, the two metallic parts that form the joint must be electrically connected with conductive braid or cord.

If possible, connect the screens of the field cables to a separate compensation bar for each voltage level of the cable, according to the type of signal (analogue or digital) and the frequencies in play. Such bars will be then connected to the star centre of the ground connection network.

If possible, isolate the ground conductor of the three phase power lines, avoiding putting them in the same cable tray. This is particularly useful when the power lines are noisy as it prevents capacitive coupling with the ground conductor. If this is not possible, separate the two cable types with a conductive barrier as shown in fig. 6.

It is better if the cable trays, inside which the power cables are placed, are not connected to the compensation bar inside the cabinet, in order to avoid interference inside the cabinet – caused by inductive coupling between the cables connected to the cabinet terminal block and the loop made up of the cable tray and the ground wire.

External devices connected to the cabinet and located a long distance away should be fitted with a compensation conductor of cross section  $\geq 10 \text{ mm}^2$ . One end of this should be connected to the compensation bar of the cabinet for field connections and the other to the ground terminal of the external device, in order to reduce the coupling due to common impedance.

## **SCREENING**

Screening has the purpose of defining spaces within which emissions generated by the device itself are contained, or spaces in which it is desired to keep out interference generated outside.

To create a good screening means creating an environment very similar to that of a Faraday cage. Note that screening made with non-ferromagnetic metals, such as copper and aluminium, although effective against electrical disturbances are transparent to magnetic perturbations and thus do not offer protection against inductive coupling.

### **SCREENING THE CONTAINER**

It is often necessary to isolate sections that generate high intensity electromagnetic fields, or sections that are particularly sensitive to them, from the rest of the system.

Regarding the type of electromagnetic environment that may be expected inside an electrical cabinet, we give the following indications:

- Isolate all devices that could be sources of interference, such as transformers, enclosing them in sheet metal and connecting this casing to the compensation bars used for the ground connection of the same devices.
- If there are power cables and signals inside the same cable tray, isolate one from the other with metallic separators as shown in Fig.6. The cable tray must be connected to ground outside the cabinet in order to avoid inductive coupling.
- The containers that act as screens often have apertures that are necessary for ventilation, for the entry and exit of wires to and from the outside, indicators etc.. So that the screening effect is compromised as little as possible, make the apertures so that one dimension is much smaller than the other, remembering that the maximum dimension of the slot must be approximately 20 times less than the wavelength ( $\lambda$ ) of the signal to be screened.

### **SCREENING THE CABLES**

The purpose of screening cables is to absorb the electromagnetic interference that would otherwise give rise to noise voltages on the signal on the wire inside the screen itself. To do this, it is not enough to use double screen or high conductivity screening material, but the sleeve must be connected in the correct way.

In any case, cables of categories 2 and 3 should always be screened. Therefore **cables used to connect the controller to encoders, optical rulers, analogue transducers, motor drives or proportional valve controllers must always be screened.**

Wherever possible, it is also recommended that screened cables are used also to connect the inputs and outputs (especially for cables that run for considerable distances).

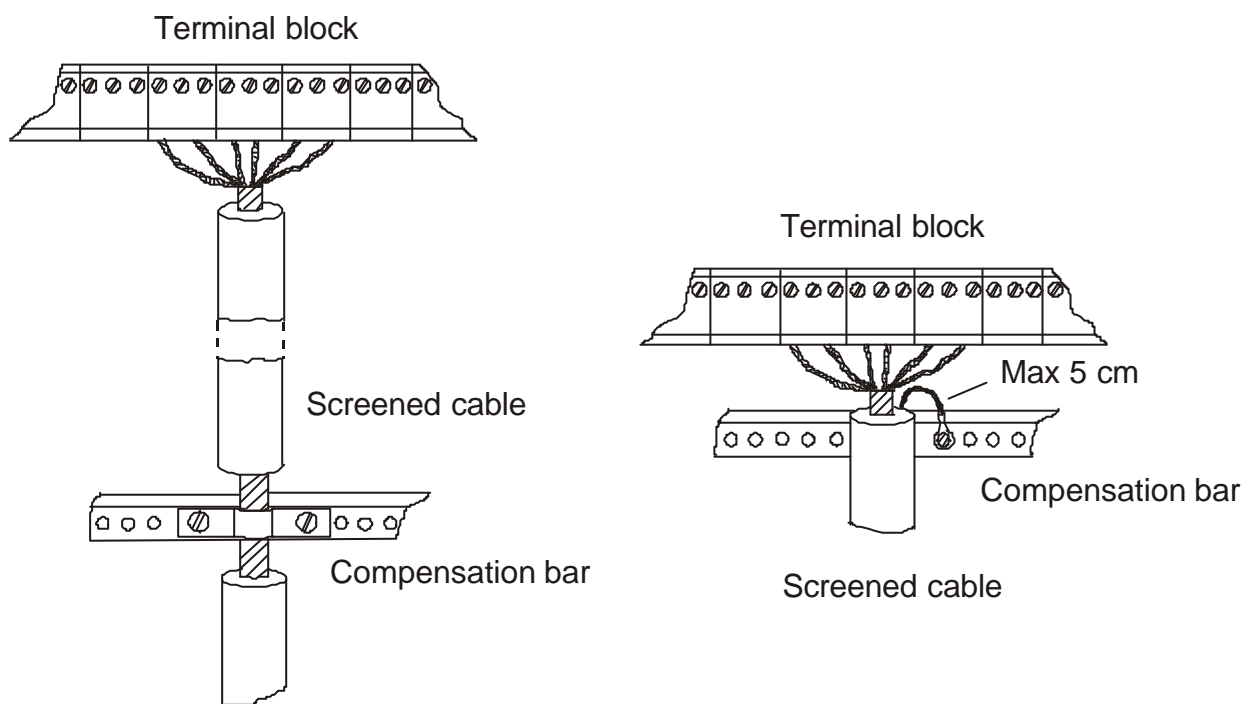
Cables of the 3<sup>rd</sup> category should be laid in suitable metallic trays with cover and separated from cables of the lower categories.



The ground connection of the screen of the cable is made **at one end only for the analogue signal, encoder signal and I/O signal cables** and **at both ends for serial communication cables**. If the screen is connected at one end only, this is the cabinet end, if the cable is external to the cabinet, or at the controller end, if the cable is inside the cabinet. Refer to the relevant chapters for cables connected to the motor drives and encoders.

For serial communications, to avoid high frequency noise, it is better to connect the ground reference of the two communicating systems to a compensation conductor of low resistance.

The screens of cables outside the cabinet must be connected to the compensation bar as shown in Fig.8 such that the length of unscreened cable is as short as possible. If an extra length of wire is needed to connect the sleeve to ground, this wire must be as short as possible.



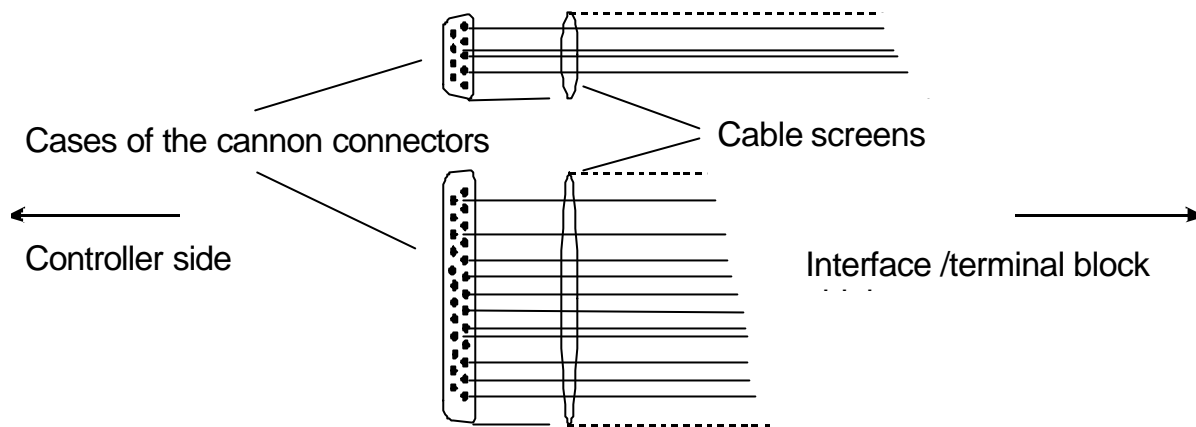
Connection of the screen when compensation bar is far from the terminal block

Connection of the screen when compensation bar is close to the terminal block

**Fig.8: Connection of the screens of field cabling to the compensation bar**

The mesh of screened cables inside the cabinet must be connected at the controller end as shown in Fig. 9.

Do not connect the screen to any pin that goes to the controller.

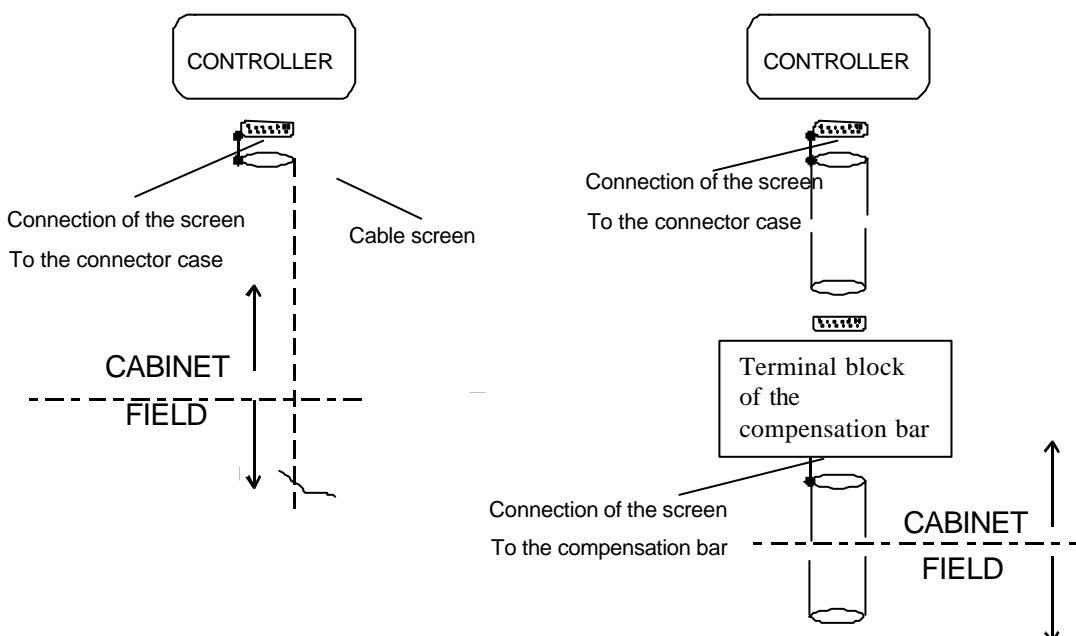


**Fig.9: Connection of the cable screens to the connector case**

Signal cables of the 3<sup>rd</sup> category must be screened both inside and outside the cabinet, their mesh sleeves must be connected to ground.

Fig. 10 shows the recommended method for connecting the screens of the analogue signal cables in the following cases:

- connection directly from the field to the controller
- connection to the controller through an interruption in the cable at the cabinet’s terminal block

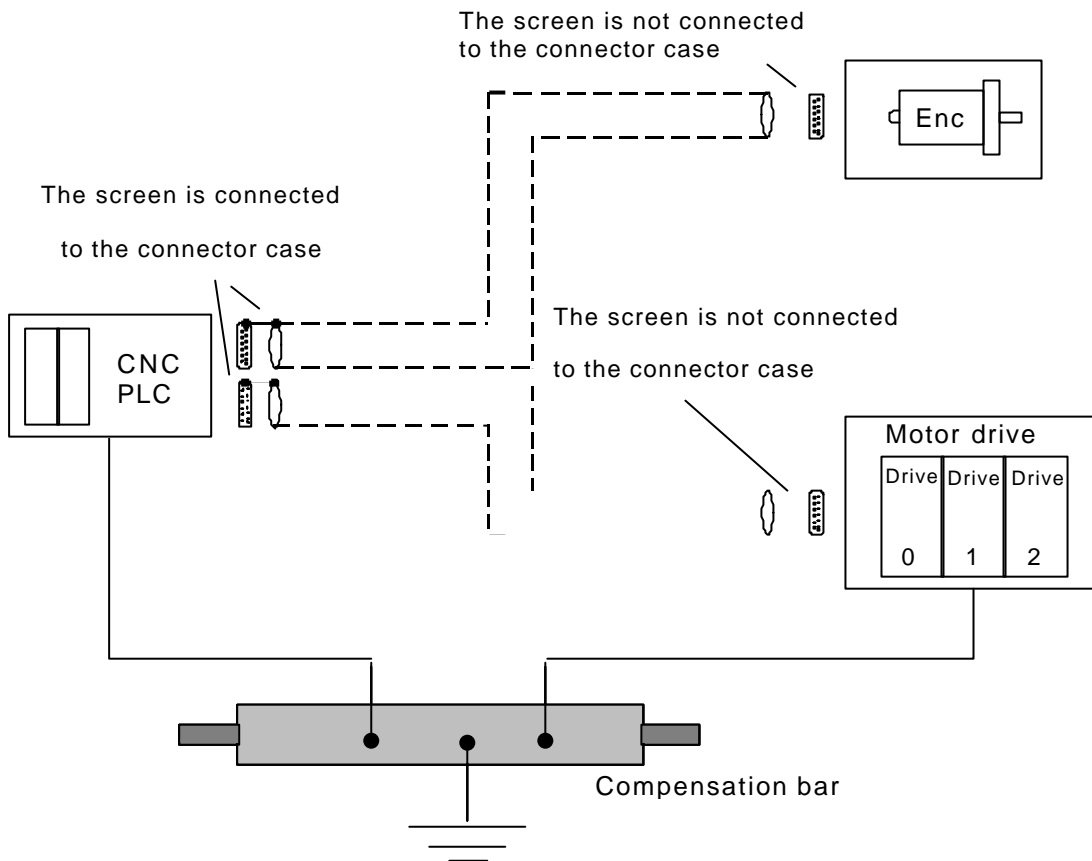


**Fig.10: Example of analogue signal cable connections**

## CONNECTION OF THE CONTROLLER TO THE ENCODER AND THE MOTOR DRIVE UNIT

The controller is connected to the encoder and to the motor drive unit using screened cable, **the screen should be soldered to the case of the connector ONLY at the controller end**, as shown in fig.11.

Encoders with differential output are preferred, taking care to use the same pair of twisted cables for each pair of differential outputs.



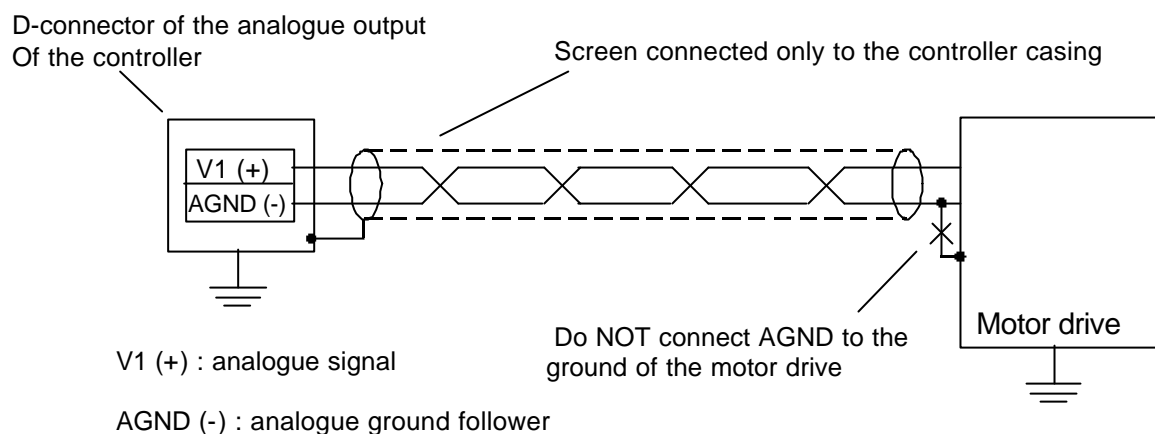
**Fig.11: Layout for the controller connections to the encoder and to the motor drive**

The motor drive and the controller are grounded using the same compensation bar (star centre of the system) with wires as short as possible and diameter  $\geq 6\text{mm}^2$ .

**MINIMISING THE EFFECT OF NOISE ON THE MOTOR DRIVE**

The connection of the analogue output of the controller to a motor drive that has a differential input for the velocity reference must be made without connecting the reference signal wire (AGND) of the analogue output to the ground at the drive end, leaving this to float (see Fig. 12).

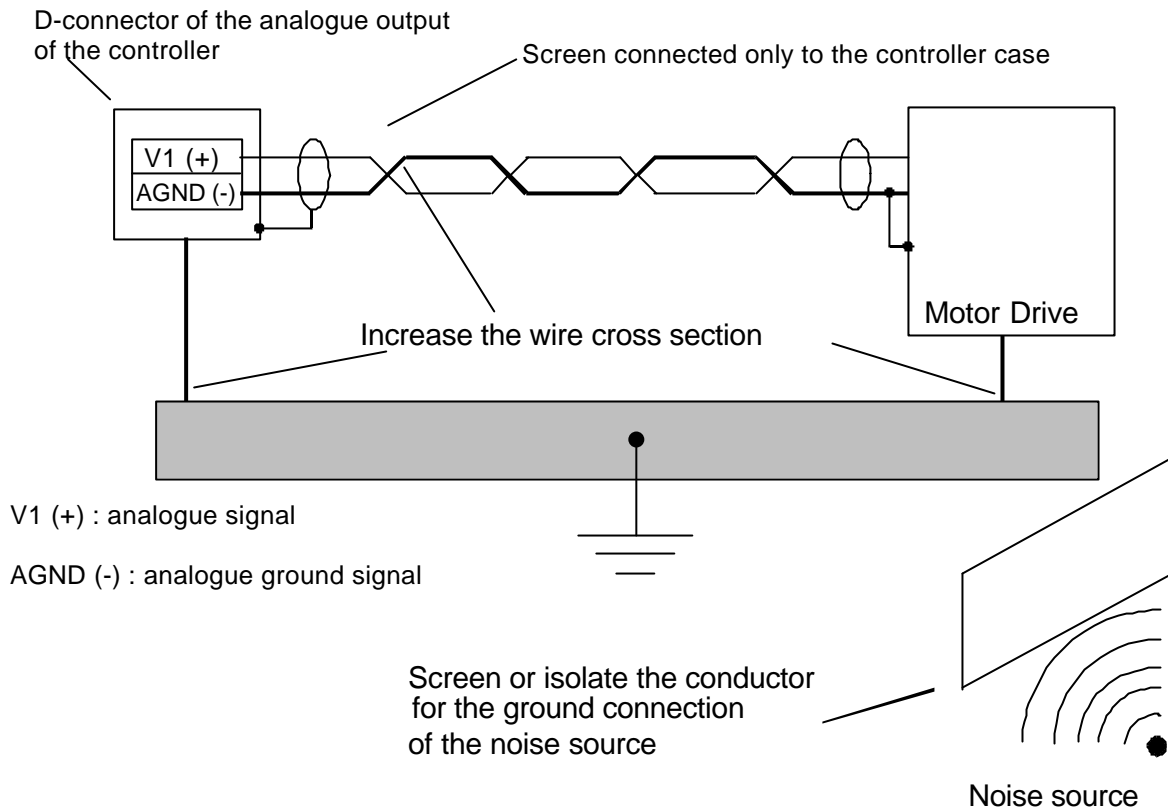
This is particularly valid for motor drives situated at a distance greater than 7-8m from the controller and/or when there is a ground network that is particularly sensitive to high frequencies.



**Fig.12: The connections from the controller to the motor drive with differential input**

If it is not possible to obtain a floating analogue output, for example if the motor drive does not have a differential input, it is recommended that (see Fig. 13):

- the cross section of the wire that is used to connect the AGND of the analogue output to the Vref of the motor drive unit (ground connection) is increased.
- the cross section of the wire of the ground system that connects the controller ground to that of the motor drive unit is increased.
- if possible, the distance between the controller and the motor drive unit is reduced and consequently the length of the connection wire kept short.
- the possible source of noise from the ground cable of the controller and the motor drive unit are kept as far apart as possible (in order to avoid coupling from common impedance).



**Fig.13: The connection of the controller to the motor drive unit with a single ended digital input**



# **CNC – APPENDIX C:**

## **CHOICE OF ENCODER**

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EXAMPLE.....	3
<b>DEFINING THE RESOLUTION.....</b>	<b>3</b>
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## GENERAL

This appendix illustrates the sequence of steps required to determine the characteristics of the encoder in relation to the needs of the application and those of the controller. In this description, it is presumed that the shaft of the motor and the shaft of the encoder are rigidly connected and that they move at the same angular velocity at all moments. If there is a gear inserted between the two systems, the ratio must be taken account of in any calculations. The procedure described below must be followed for every axis with encoder feedback that the application has fitted.

## TYPES OF AXES AND DEFINING THE TRANSMISSION RATIO

The axes of the numerical control are described as LINEAR AXES AND ANGULAR AXES.

### LINEAR AXES

Linear axes can be constructed by way of telekinetic transmission, in which the moving part is moved by a flexible transmission (belt, steel rope, chain) in turn acted upon by a pinion or by a pulley fixed to the motor shaft, or, they could be constructed by way of transmission through a screw, in which linear movement is obtained thanks to the axial movement relative to the two parts that takes place when one of them is rotated by the motor and the other cannot follow the rotation. All LINEAR AXES are characterised by having their travel limited in both directions of movement.

In the case of of linear axis, the transmission ratio  $K_T$  is defined as the linear displacement that is obtained with one complete revolution of the motor shaft.

#### Examples:

- 1) Linear axis with telekinetic transmission through toothed belt:  
Primitive diameter of the drive pulley: 40mm  
Linear displacement for one revolution:  $\pi \times 40 \text{ mm} \cong 125.664 \text{ mm}$   
Transmission ratio:  $K_T = 125.664 \text{ mm/rev.}$
- 2) Screw driven linear axis:  
Screw pitch: 5mm  
Transmission ratio:  $K_T = 5 \text{ mm/rev.}$

Naturally it is possible to introduce a reduction between the motor and the moved device, either a motorised pulley in the case of telekinetic transmission or a mechanical gear for the screw drive. If there is a reduction, the ratio must be considered when calculating the transmission ratio.

Imagine using a reduction of 1/10 in example 1. The transmission ratio becomes 12.5664 mm/rev.



## ANGULAR AXES

The ANGULAR AXES (or polar axes) are in all effects reducible to controlled motorised reduction gears. These axes can have limited travel, for example for polar movement of a manipulating arm, or unlimited, as for the case of a rotating table. The transmission ratio  $K_T$  in this case is obtained directly from the reduction ratio.

### Example

Reduction ratio: 1/50

$$\text{Transmission ratio: } K_T = 360^\circ \times \frac{1}{50} = 7.2^\circ/\text{rev.}$$

## DEFINING THE RESOLUTION

The resolution of the axis is the smallest entity of displacement that the system can effect. It is fundamental to distinguish between resolution and accuracy.

- The resolution may be calculated exactly on the basis of the transmission ratio and the number of notches that the encoder disc has around its circumference, for d.c. motor driven axes, or on the basis of the transmission ratio and the number of steps/rev., for axes driven in frequency.
- The accuracy depends not only on the resolution, but also on the mechanical play and severity/rapidity of the reaction of the system to a position error. It cannot be calculated theoretically but must be verified in practice both for a static position and for dynamic accuracy during movement.

As a general rule, it is considered that the accuracy can never be better than double the resolution, even when there is no play and brushless motors are used. The more play there is between parts and the slower the motors, the worse will be the accuracy of the system. It is therefore better to maintain a good margin of error: for analogue driven axes, the encoder resolution must be chosen between 5 and 10 times better than the required accuracy, without forgetting that the larger the number of notches, the higher the cost of the device and higher the maximum frequency.

The opposite argument applies for frequency driven axes. In this case the resolution of the axes is defined by the elementary displacement of the motor, while the encoder checks the accuracy of the entire system. In this case therefore, it is necessary to adopt an encoder with a resolution that is worse than the resolution by at least a factor of 2 with respect to the axis resolution (e.g.: motor with 400 steps/rev., encoder 200 notches), otherwise the motor will hunt around a position in which it should remain stationary. Whenever there are constraints that prevent this rule from being applied, it will be necessary to use the dead band setting to prevent hunting (see appendix F – CALIBRATION OF THE AXES).

The encoder resolution is obtained from the formula:

$$R = \frac{K_T}{4 \times N}, \text{ where}$$

R = resolution  
K<sub>T</sub> = transmission ratio  
N = number of notches in the encoder

The factor of 4 that appears in the denominator takes into account the multiplication by four of the encoder pulses that all the S&h controllers do automatically. Referring to example 2 on the previous page, where K<sub>T</sub> = 5 mm/rev. and imagining using an encoder with 500 notches, the resolution will be

$$R = \frac{5 \text{ mm/rev.}}{4 \times 500/\text{rev.}} = 2.5 \mu\text{m.}$$

Obviously, in the case of angular axes, the resolution is obtained as a fraction of a sexagesimal degree.

## **CHOICE OF THE NUMBER OF NOTCHES/REVOLUTION**

Noting the desired resolution for the axis, and applying the previous formula in reverse, it is possible to calculate the necessary number of notches. However, encoders are manufactured with standard numbers of notches, at least for production models, and it is advisable not to order a custom version. For example, if K<sub>T</sub> = 6 mm and R = 10 μm (one hundredth of a millimetre), the number of notches will be:

$$N = \frac{K_T}{4 \times R} = \frac{6 \text{ mm/rev.}}{4 \times 0.01 \text{ mm}} = 150/\text{rev.}, \text{ where}$$

N = number of encoder notches  
K<sub>T</sub> = transmission ratio  
R = resolution

Since 150 is not a standard value, an encoder of 200 or 300 notches could be used, obtaining a better resolution than required.

## **CHECKING THE MAXIMUM FREQUENCY**

All controllers have a maximum limit to the frequency of the signal that they can accept from the encoder. The maximum allowed frequency is indicated in the technical specification inside the users' manual of the chosen controller.

The maximum frequency depends on the velocity of rotation of the motor, expressed in revolutions per minute or r.p.m.), and the number of notches on the encoder, according to the formula:

$$f_{\text{MAX}} = \frac{\omega_{\text{MAX}}}{60} \times 4 \times N, \text{ where}$$

f<sub>MAX</sub> = maximum frequency for the controller  
ω<sub>MAX</sub> = maximum velocity of the motor  
N = number of notches on the encoder

As usual, the factor of 4 takes into account that the controller multiplies the number of encoder pulses by 4. The constant 60 in the denominator is due to the fact that  $\omega_{MAX}$  is expressed in r.p.m., while  $f_{MAX}$  is expressed in Hertz (cycles/second).

For example, imagine an encoder with 1000 notches mounted on a motor that rotates at a maximum of 3000 r.p.m. The maximum frequency will be:

$$f_{MAX} = \frac{3000 \text{ r.p.m.}}{60} \times 4 \times 1000/\text{rev.} = 200 \text{ kHz (200,000 cycles/second)}$$

**Always check that the maximum frequency does not exceed the limits of the chosen controller.**

**Remember that, even in the case where the the motor will always be used at a lower velocity than its rated maximum, the calculation must be made on the basis of the maximum speed that the motor can reach because the reaction loop can superimpose itself over the programmed instruction, making the motor run at a much higher speed than that assumed for the theoretical calculations.**



# **CNC – APPENDIX D:**

## **INSTALLATION OF THE MOTOR DRIVES**

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VOLTAGE CONTROL.....	4
<b>SOFTWARE CONFIGURATION .....</b>	<b>6</b>
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## GENERAL

In this appendix, some recommendations are made for the connection of the motor drives to the S&h controllers. There are two categories of motor drive commercially available commanded by a frequency modulated logic signal, in one case, or a voltage modulated analogue signal in the other. There are differences between the two cases and they will be described separately.

## PHYSICAL CONNECTION

All S&h controllers have specialised connectors that distinguish the motor drive signal cables from all the others. To localise the connection points, refer to the users' documentation for the particular controller.

The connection to the motor drive must be made using a screened cable that distinguishes it from the other cables. The mesh screen of the cable must be connected to the metal casing of the connector only at the end connected to the controller. In the appendix on "Electromagnetic Interference", the user can find a series of useful indications as to how the cabling should be made so as to minimise the effects of external interference.

All the outputs of the controller towards the motor drive are NPN open collector type, therefore, if the driver does not have internal pull up resistors, these must be fitted externally. In treating the high frequency signals, pay particular attention not to exceed the 125mA that the controller output can supply and to the capacitance of the output transistor collector: too high a value of the pull-up can operate well at low frequencies and not function at all at higher frequencies. The external pull-up resistor must be located near the motor drive and must be referred to the correct supply voltage indicated in the documentation for the device.

Some motor drives have inputs that are totally incompatible with the NPN open-collector output of S&h controllers. For signals that rarely change, such as "Enable", it is possible to drive the coil of a relay with the output of the controller and use the changeover contacts to command the motor drive unit. For more critical signals, such as "Dir" and above all "Pulse", refer to the appendix "Solutions of Incompatibility problems"

Accepting that the cable between the controller and the motor drive unit must be as short as possible and of very high quality, remember also that the higher the frequency or the resolution, the more significant will be the attenuation and the distortion introduced by the cable. As an indication, the following table shows the maximum cable length as a function of frequency for a cable of capacitance of 100pF/m and with a 4k7 pull-up resistor.

Frequency	Length
8 kHz	50 m
80 kHz	5 m
800 kHz	0.5 m

### CONTROL SIGNALS IN FREQUENCY

Figure 1 shows the connection between the controller and a motor drive unit driven by a frequency modulated logic signal. In it the following control signals can be recognised.

**Pulse:** This is the output of the controller, in frequency, through which the velocity of the motor is controlled. The velocity is directly proportional to the frequency sent. The maximum frequency at the output is specified in the users' manual for the controller used, while the frequency that corresponds to the maximum velocity of the motor is to be found in the documentation for the motor drive unit.

**Dir:** This is the output that determines the direction of rotation of the motor. The sign of the algebraic difference between the co-ordinates at which the axis must find itself at the end of the movement and the co-ordinate at which it finds itself at the beginning defines the direction of rotation. For example, if the axis finds itself at co-ordinate 100mm and must go to co-ordinate 200mm, the difference is +100 and the direction of movement is positive. If the axis is at position 200mm and must go to 0mm, the difference is -200 and the direction is negative. The correspondence between the direction of movement (+ or -) and the state of the output **Dir** (1 or 0, or, 0 or 1) is programmable in the controller.

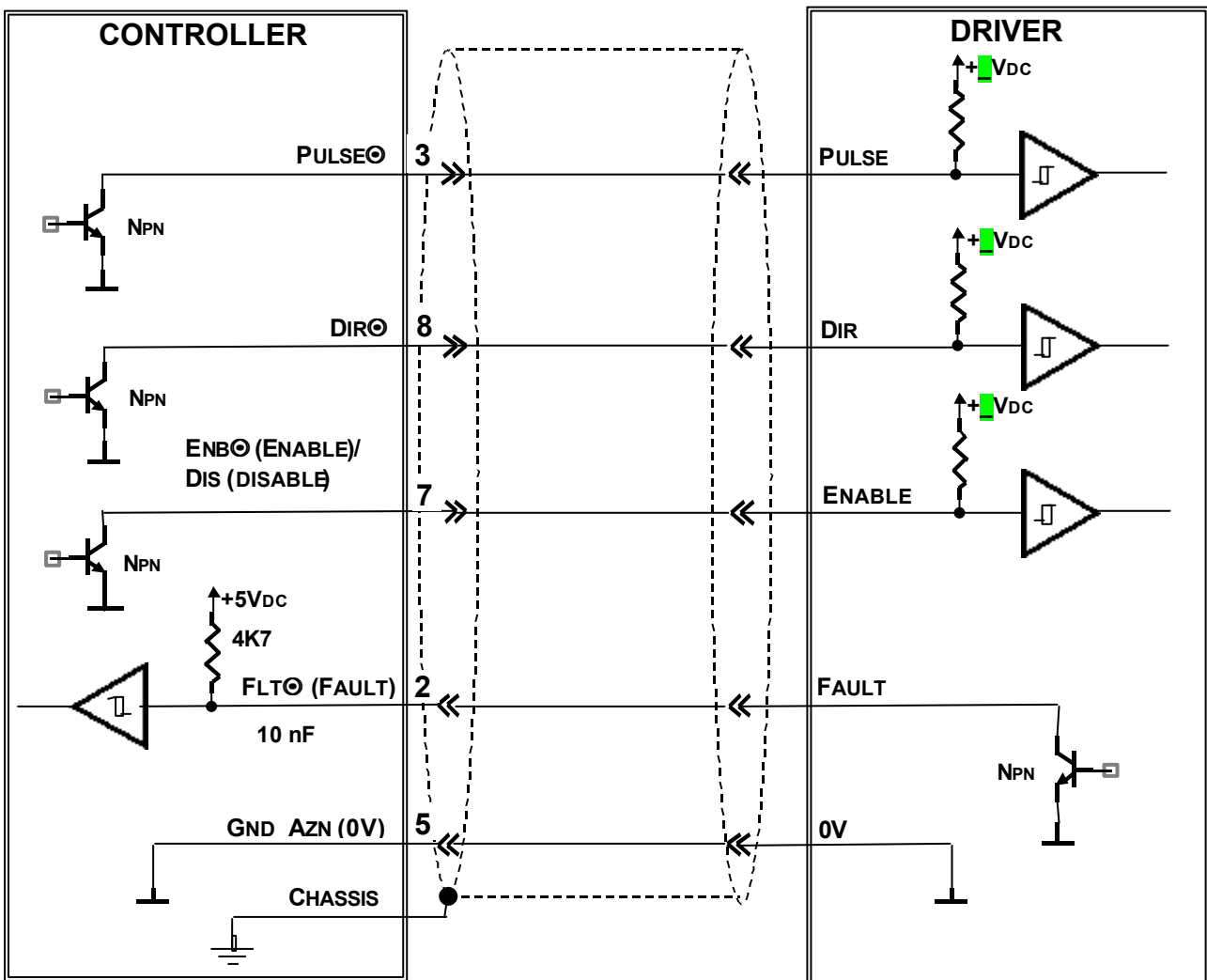


Fig. 1: Connections for a frequency controlled motor drive unit.

**Enable/Disable:** This is the output to enable the motor drive. When the drive is disabled, it does not send any current to the motor and ignores any information that may be sent to the other inputs such as the frequency input or analogue signal input. The state of this output is programmable from the controller so that it can control the drive unit correctly in an emergency.

**Fault:** This is an input with pull-up on the controller to which is sent the fault signal generated by the motor drive unit. In normal conditions, the Fault output of the motor drive unit is closed to ground. Although the input of the controller is protected against over-voltage by a resistance in series and clamping diodes towards ground and towards the +5V rail, it is recommended that the input is protected against a voltage greater than +24V and lower than 0V

**GND\_AZN:** This is the ground connection (voltage reference) of the interface between the controller and the motor drive.

### ***VOLTAGE CONTROL***

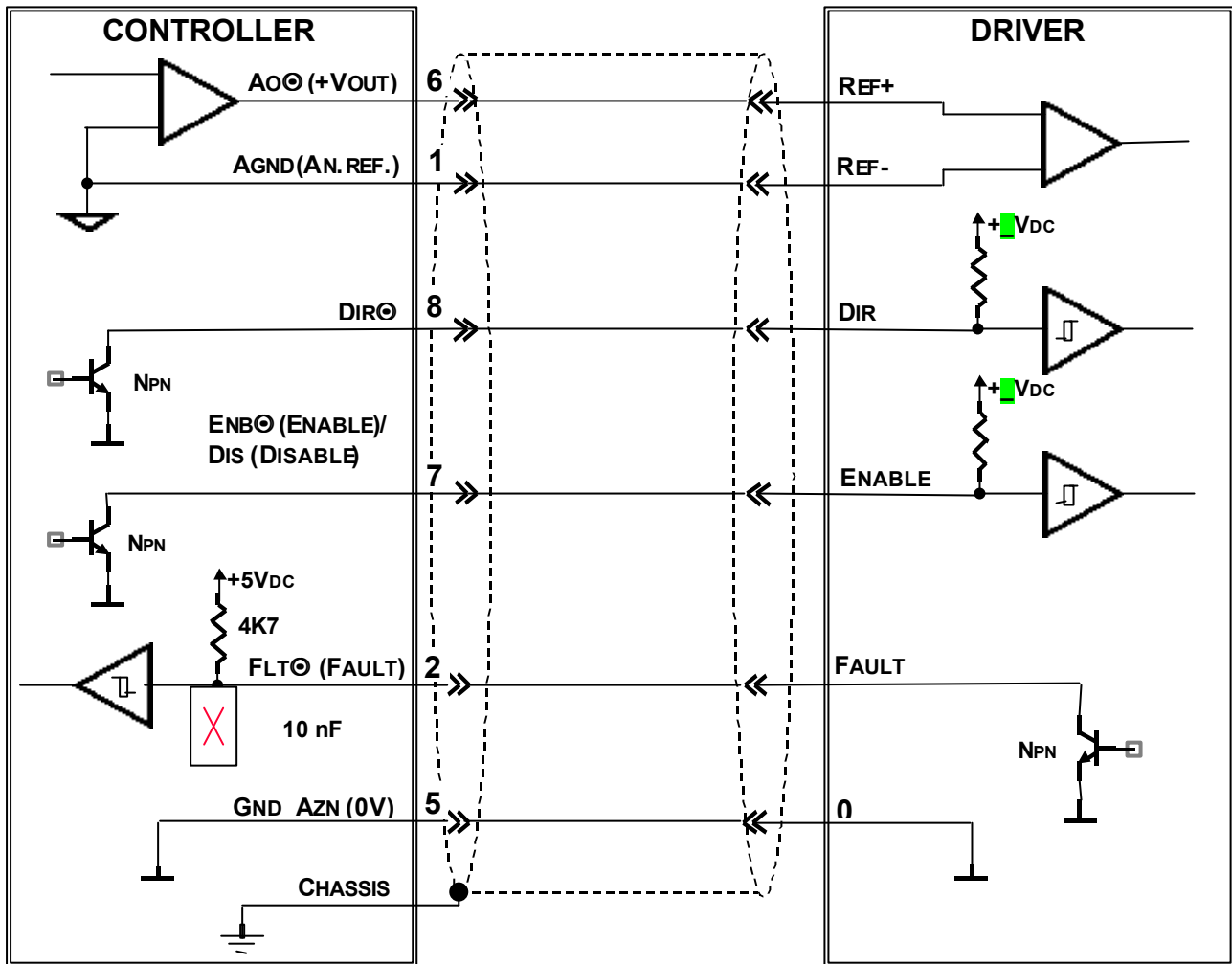
Figure 2 shows the connections between the controller and a motor drive unit controlled by a modulated analogue voltage signal. In this diagram, the following signals are seen.

**+VOUT:** This is the analogue output whose voltage is proportional to the speed of the motor. For some motor drives it can have both positive and negative values (bipolar analogue voltage) and the sign of the voltage defines the direction or rotation of the motor. In other cases, the motor drive can accept only positive voltage (unipolar analogue voltage), while the direction of rotation must be indicated by a Dir signal. For this it is possible to program the controller to supply the suitable analogue output. The voltage range generated by the controller is always  $\pm 10V$ , which can be limited with program instructions. Its resolution depends on the controller used. The relative information is to be found in the users' manual of the controller. The motor drive unit's documentation is needed to find out what voltage corresponds to the maximum speed of the motor.

**AGND:** This is the reference for the analogue control signal. Normally the motor drive unit has a specific connection point for the return of the analogue signal, which is distinct from the ground of the interface towards the controller. Whenever the chosen drive does not have this connection, AGND must be connected to the closest possible ground connection and it will be necessary to pay attention to possible sources of interference to the system. For more information, refer to the appendices "Application notes for S&h controllers" and "Electromagnetic Interference".

**Dir:** This is the output that determines the direction of rotation of the motor. The drive unit is not always controlled by the voltage present at this output. The sign of the algebraic difference between the co-ordinates of the axis at the beginning and the end of the movement defines the direction of movement. For example, if the axis is at co-ordinate 100mm and it must go to 200mm, the difference is +100 and the direction of movement is positive. If the axis is in position 200mm and must go towards 0mm, the difference is -200 and the direction is negative. The correspondence between the direction of movement (+ or -) and the state of the Dir output (1 or 0, or, 0 or 1) is programmable in the controller.





**Fig. 2: Connection of a voltage controlled motor drive unit.**

**Enable/Disable:** This is the output for enabling the drive unit. When the drive is disabled, it does not send any current to the motor and ignores any eventual information sent to the frequency or analogue input. The state of this output is programmable on the controller so that the correct signal will be sent to control the drive in case of an emergency.

**Fault:** This is an input with pull-up inside the controller which must receive the fault signal generated by the drive unit. In normal operation, the Fault output of the drive is closed to ground. Although the input to the controller is protected against over-voltage by a series resistance and clamping diodes towards the ground and +5V rail, it is recommended that this input should not be allowed to receive signals greater than +24V or less than 0V.

**GND\_AZN:** This is the ground connection (voltage reference) of the interface between the controller and the motor drive.

## SOFTWARE CONFIGURATION

The purpose of the software configuration of the controller is to supply it with all the information it needs for a correct interpretation of the signals that the system supplies to it and also to adapt its own output signals to the characteristics of the other elements in the system. To this end, a few @ instructions are used. The controller can be configured using its display and keypad, when these are available, or using the Bach software package for any S&h controller.

It is possible to distinguish three different cases according to the control mode of the motor drive unit.

- Frequency control with eventual feedback in frequency
- Unipolar analogue control with feedback in frequency
- Bipolar analogue control with feedback in frequency

The following paragraphs explain the parameters that must be configured for each of the three cases. For greater detail about these instructions, refer to the CNC programming manual.

When the Bach program is available, the access to all the parameters is facilitated by the dedicated data input menus. The @ code that corresponds to the parameter on which the cursor is placed will be shown each time in the hint-box (the yellow suggestion flag that appears if the pointer is left stationary on an active field).

If the controller interface or programming terminal is used for the parameters, remember that it is possible to verify what the controller has received with the series of % codes. For example, with the string "@31X1" a value is assigned to the motor direction parameter of the X-axis. Using the string %31, the reply returns "X1Y..." for all the axes controlled, from which it is seen that the instruction "@31X1" has been received and executed correctly.

The indications regarding the mode or checking the correct setting of the parameters are shown each time, immediately after the description of the sequence for making the entry.

### **Important:**

To prevent damage to property and injury to persons, check carefully the correct setting of the parameters entered, wherever possible, with the motors free, i.e. not connected mechanically with the components that they move.

If for some reason it is not possible to disconnect the transmission, take all possible care that no damage can occur as a result of an unexpected and uncontrolled movement of the motors.

**FREQUENCY CONTROL WITH EVENTUAL ENCODER FEEDBACK**

For simplicity, all the examples of strings that are shown in this description refer to the X-axis. It may be taken as granted that identical syntax is used for all the other axes present. For all other parameters, it is possible to specify the value for each axis separately or for more than one axis. For example, the string “@31X1Y0Z2W1” specific to the parameter @31 for all four axes.

The procedure indicated here does not take into account the correspondence between engineering units and motor pulses nor the maximum allowed frequency of the motor and its drive. For defining these parameters, see the appendix regarding the calculation and setting of the axes’ parameters.

**Setting parameters**

**@31:** Defines the direction of the drive (logic of the Dir signal).

For the controller, the Dir signal is active when the direction of movement is positive, i.e. when the algebraic difference between the target co-ordinate and the co-ordinate of the beginning of the movement has a positive sign. The string “@31X2” is used to disable the output and the Dir signal will not be controlled. For other cases, see the following table.

Parameter	Direction	Output State
@31X0	Positive	Open
	Negative	Closed to GND
@31X1	Positive	Closed to GND
	Negative	Open

**@32:** Defines the enabling of the drive (logic of the Enable or Disable signals)

For the controller, the “Enable” output is active when the motor drive can move the axis and is inactive when the drive is disabled, for example in an emergency condition. The opposite is true for the Goya controller.

Even here, the string “@32X2” implies that the relative signal is disabled and therefore remains open. In all other cases, the following table applies.

Parameter	Enable	Output State
@32X0	Active	Open
	Inactive	Closed to GND
@32X1	Active	Closed to GND
	Inactive	Open

For the Goya only, the following table applies.

Parameter	Disable	Output State
@32X0	Active	Closed to GND
	Inactive	Open
@32X1	Active	Open
	Inactive	Closed to GND

**@5:** defines the OK signal of the drive (logic of the Fault signal).

With this instruction, it is possible to enable or disable the input dedicated to the “Drive OK/Fault” from the motor drive unit and program the active state. “@5X2” is used to disable the input. For other cases, see the following table.

Parameter	Input State	Controller condition
@5X0	Input open or to +24V	Emergency
	Input closed to GND	Operational
@5X1	Input open or to +24V	Operational
	Input closed to GND	Emergency

### Check

When the function of a system complete with feedback is checked (actual position signal generated by an encoder or optical ruler), it is possible to encounter a problem of phase where the input signal moves in the opposite direction to that moved by the system. For example, if the encoder connections are inverted, the count will proceed in the opposite direction to that the controller expects. Similar problems will occur if the logic programmed for the Dir signal has been inverted. The effect of this type of situation is that the motor runs away at its maximum speed as soon as it is enabled. Not being able to predict the direction in which the axis will move can make the emergency intervention for servo error ineffective (emergency for excessive follow error).

For this reason, it is strongly advised that the checks described here are performed excluding the position feedback. This can be done simply by sending the string “@40X0”. Later, reprogramming the correct value for the emergency intervention for follow error, the function of the feedback system will be re-enabled.

**@5:** Define drive OK (logic of the Fault signal)

Power up the system and check that the controller is not in emergency due to the signal from the motor drive unit.

**@32:** Define the enable state of the motor drive unit (logic of the Enable/Disable signal)

- Check that the drive is operational: normally the drive has an LED to indicate its state.
- Put the controller into emergency using the control panel, or sending it the ^K code and check that the drive becomes disabled.
- Reset the controller emergency using its control panel or sending the ^L code and check that the drive becomes operational again.

**@31:** Define drive direction

Perform a displacement of the axis using a manual instruction or sending an instruction such as “G0X100” followed by “G0X0”, checking that the direction of movement is the correct one.

**UNIPOLAR ANALOGUE CONTROL**

For simplicity, all the examples of strings that are shown in this description refer to the X-axis. It may be taken as granted that identical syntax is used for all the other axes present. For all other parameters, it is possible to specify the value for each axis separately or for more than one axis. For example, the string “@31X1Y0Z2W1” specific to the parameter @31 for all four axes.

The procedure indicated here does not take into account the correspondence between engineering units and motor pulses nor the allowed voltage range of the motor drive. For defining these parameters, see the appendix regarding the calculation and setting of the axes' parameters.

**Setting parameters**

**@31:** Define drive direction (logic of the Dir signal).

For the controller, the Dir signal is active when the direction of movement is positive, i.e. when the algebraic difference between the target co-ordinate and the co-ordinate of the beginning of the movement has a positive sign. The string “@31X2” is used to disable the output and the Dir signal will not be controlled. For other cases, see the following table.

Parameter	Direction	Output State
@31X0	Positive	Open
	Negative	Closed to GND
@31X1	Positive	Closed to GND
	Negative	Open

**@32:** Defines the enabling of the drive (logic of the Enable or Disable signals)

For the controller, the “Enable” output is active when the motor drive can move the axis and is inactive when the drive is disabled, for example in an emergency condition. The opposite is true for the Goya controller.

Even here, the string “@32X2” implies that the relative signal is disabled and therefore remains open. In all other cases, the following table applies.

Parameter	Enable	Output State
@32X0	Active	Open
	Inactive	Closed to GND
@32X1	Active	Closed to GND
	Inactive	Open

For the Goya only, the following table applies.

Parameter	Disable	Output State
@32X0	Active	Closed to GND
	Inactive	Open
@32X1	Active	Open
	Inactive	Closed to GND

**@33:** defines the type of analogue output (Unipolar/Bipolar)

The parameters is specified with the string “@33X1”

**@5:** defines the OK signal of the drive (logic of the Fault signal).

With this instruction, it is possible to enable or disable the input dedicated to the “Drive OK/Fault” from the motor drive unit and program the active state. “@5X2” is used to disable the input. For other cases, see the following table.

Parameter	Input State	Controller condition
@5X0	Input open or to +24V	Emergency
	Input closed to GND	Operational
@5X1	Input open or to +24V	Operational
	Input closed to GND	Emergency

### Check

When the function of a system complete with feedback is checked (actual position signal generated by an encoder or optical ruler), it is possible to encounter a problem of phase where the input signal moves in the opposite direction to that moved by the system. For example, if the encoder connections are inverted, the count will proceed in the opposite direction to that the controller expects. Similar problems will occur if the logic programmed for the Dir signal has been inverted. The effect of this type of situation is that the motor runs away at its maximum speed as soon as it is enabled. Not being able to predict the direction in which the axis will move can make the emergency intervention for servo error ineffective (emergency for excessive follow error).

For this reason, it is strongly advised that the checks described here are performed excluding the position feedback. This can be done simply by sending the string “@40X0”. Later, reprogramming the correct value for the emergency intervention for follow error, the function of the feedback system will be re-enabled.

**@5:** Define drive OK (logic of the Fault signal)

Power up the system and check that the controller is not in emergency due to the signal from the motor drive unit.

**@32:** Define the enable state of the motor drive unit (logic of the Enable/Disable signal)

- Check that the drive is operational: normally the drive has an LED to indicate its state.
- Put the controller into emergency using the control panel, or sending it the ^K code and check that the drive becomes disabled.
- Reset the controller emergency using its control panel or sending the ^L code and check that the drive becomes operational again.

**@31:** Define drive direction and **@33:** define type of analogue output

Perform a displacement of the axis using a manual instruction or sending an instruction such as “G0X100” followed by “G0X0”, checking that the direction of movement is the correct one. If the axis moves in one direction but not the other, check the analogue voltage generated using a multimeter and check whether it is negative. In this case check that @33 has been specified correctly.

**BIPOLAR ANALOGUE CONTROL**

For simplicity, all the examples of strings that are shown in this description refer to the X-axis. It may be taken as granted that identical syntax is used for all the other axes present. For all other parameters, it is possible to specify the value for each axis separately or for more than one axis. For example, the string “@31X1Y0Z2W1” specific to the parameter @31 for all four axes.

The procedure indicated here does not take into account the correspondence between engineering units and motor pulses nor the allowed voltage range of the motor drive. For defining these parameters, see the appendix regarding the calculation and setting of the axes’ parameters.

**Setting parameters**

**@32:** Defines the enabling of the drive (logic of the Enable or Disable signals)

For the controller, the “Enable” output is active when the motor drive can move the axis and is inactive when the drive is disabled, for example in an emergency condition. The opposite is true for the Goya controller.

Even here, the string “@32X2” implies that the relative signal is disabled and therefore remains open. In all other cases, the following table applies.

Parameter	Enable	Output State
@32X0	Active	Open
	Inactive	Closed to GND
@32X1	Active	Closed to GND
	Inactive	Open

For the Goya only, the following table applies.

Parameter	Disable	Output State
@32X0	Active	Closed to GND
	Inactive	Open
@32X1	Active	Open
	Inactive	Closed to GND

**@33:** defines the type of analogue output (Unipolar/Bipolar)

The parameter is specified with the string “@33X1”

**@34:** Define polarity of analogue output

With this parameter, the correspondence between the direction of movement and the analogue signal polarity generated by the controller is defined, according to the following table.

Parameter	Direction	Analogue signal Polarity
@34X0	Positive	Negative
	Negative	Positive
@34X1	Positive	Positive
	Negative	Negative

**@5:** Define drive OK (logic of the Fault signal)

Power up the system and check that the controller is not in emergency due to the “Drive OK/Fault” signal from the motor drive unit and program the active state. The string “@X5X2” disables this input, otherwise refer to the following table.

Parameter	Input State	Controller condition
@5X0	Input open or to +24V	Emergency
	Input closed to GND	Operational
@5X1	Input open or to +24V	Operational
	Input closed to GND	Emergency

**Check**

When the function of a system complete with feedback is checked (actual position signal generated by an encoder or optical ruler), it is possible to encounter a problem of phase where the input signal moves in the opposite direction to that moved by the system. For example, if the encoder connections are inverted, the count will proceed in the opposite direction to that the controller expects. Similar problems will occur if the logic programmed for the Dir signal has been inverted. The effect of this type of situation is that the motor runs away at its maximum speed as soon as it is enabled. Not being able to predict the direction in which the axis will move can make the emergency intervention for servo error ineffective (emergency for excessive follow error).

For this reason, it is strongly advised that the checks described here are performed excluding the position feedback. This can be done simply by sending the string “@40X0”. Later, reprogramming the correct value for the emergency intervention for follow error, the function of the feedback system will be re-enabled.

**@5:** Define drive OK (logic of the Fault signal)

Power up the system and check that the controller is not in emergency due to the signal from the motor drive unit.

**@32:** Define the enable state of the motor drive unit (logic of the Enable/Disable signal)

- Check that the drive is operational: normally the drive has an LED to indicate its state.
- Put the controller into emergency using the control panel, or sending it the ^K code and check that the drive becomes disabled.
- Reset the controller emergency using its control panel or sending the ^L code and check that the drive becomes operational again.

**@33:** define type of analogue output and **@34:** define polarity of analogue output

Perform a displacement of the axis using a manual instruction or sending an instruction such as “G0X100” followed by “G0X0”, checking that the direction of movement is the correct one. If the axis moves in one direction but not the other, it is almost certain that parameter @33 has been specified incorrectly.



# ***CNC – APPENDIX E:***

## ***ENCODER CONNECTION***

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APPENDIX VERSION : 1.1

MANUAL CODE: MA CNC U APPE 11  
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## **GENERAL**

This appendix contains instructions for connecting encoders to S&h controllers. There are two types of encoder commercially available, unipolar and differential.

The unipolar output has only one connection point for each signal generated by the encoder. This is a logic signal that has both advantages and disadvantages. The output impedance is very high and the input circuit is therefore subject to interference.

The differential output has two connection points for each signal generated. There are two logic signals at these points that are equal and opposite in phase. This solution means that they can be used like a receiver with very high immunity to interference which the S&h controllers can take advantage of.

It is therefore strongly advised that a differential encoder is used in all circumstances and it is indispensable when the cable length is greater than 3 metres or if the working environment is subject to particularly high electromagnetic interference.

## **PHYSICAL CONNECTIONS**

When ordering it is necessary to specify the supply voltage and type of input (unipolar or differential). Commercially available there are encoders that require 5V, 12V and 24V. Some S&h controllers can only supply 5V, others can supply 5V or 12V, according to the configuration. It is however always possible, providing it is specified on the order, to use an external supply from a suitable power supply unit.

Whenever it is needed to modify this order option, it is only possible to do so inside the controller. Usually these modifications can only be performed in the factory of S&h to guarantee the integrity and the correct operation of the controller. Before connecting an encoder, check that the characteristics of the controller on the configuration sheet attached to the equipment corresponds to that specified in the order.

For the connection, be careful with the following items

- Use a screened twisted pair cable for connecting the encoder.
- The screen must be isolated and connected to the casing of the connector at the controller end only.
- The connection of the screen must be made as close as possible to the casing of the connector itself.

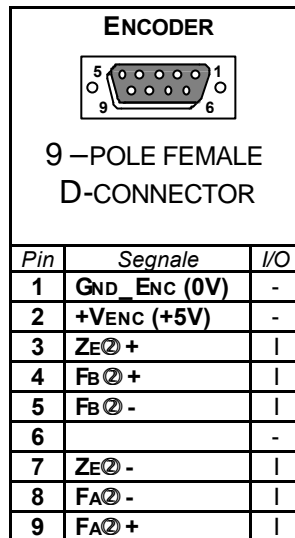
For further information on the subject of the precautions to be made when connecting the cables, refer to the appendix on “Electromagnetic interference”.

The encoder connection is made differently according to the type of interface and the way the power supply is connected. Almost all the encoders with differential output require 5V supply and the current drain is easily supported by the internal power supply in the controller. It is therefore strongly recommended that whenever possible the supply available on the connector pins is used, not only for economy but also for the rationalisation of the cables and electromagnetic immunity.

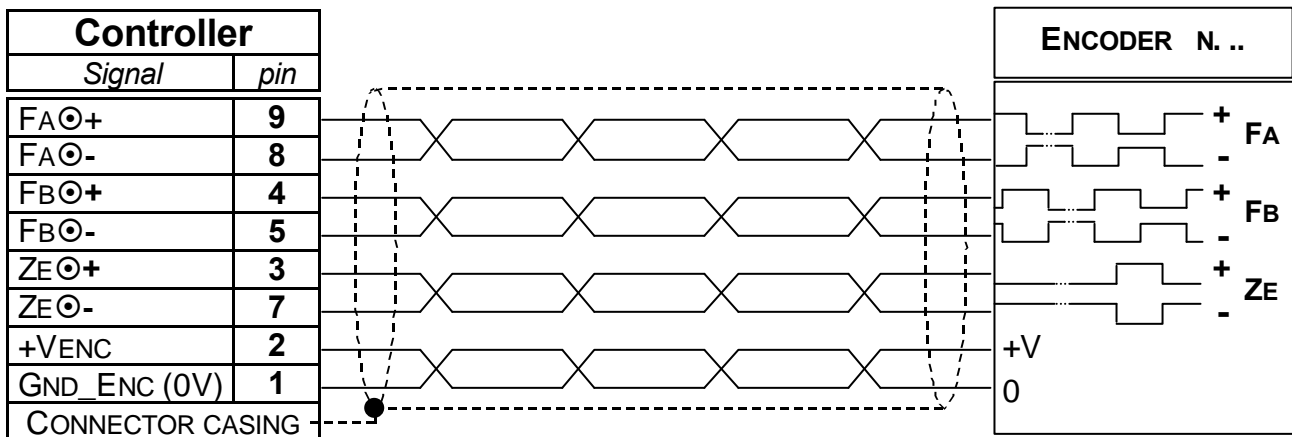
The following paragraphs show the connections required for these three different cases.

- Differential interface and internal supply
- Unipolar interface and internal supply
- Unipolar interface and external supply

Figure 1 shows the layout of the contacts on the encoder connector used on all S&h controllers. The three following drawings show the connections for the three cases listed above.



**Fig. 1: Standard S&h encoder connector.**



**Fig. 2: Connections for differential encoder using internal power supply.**

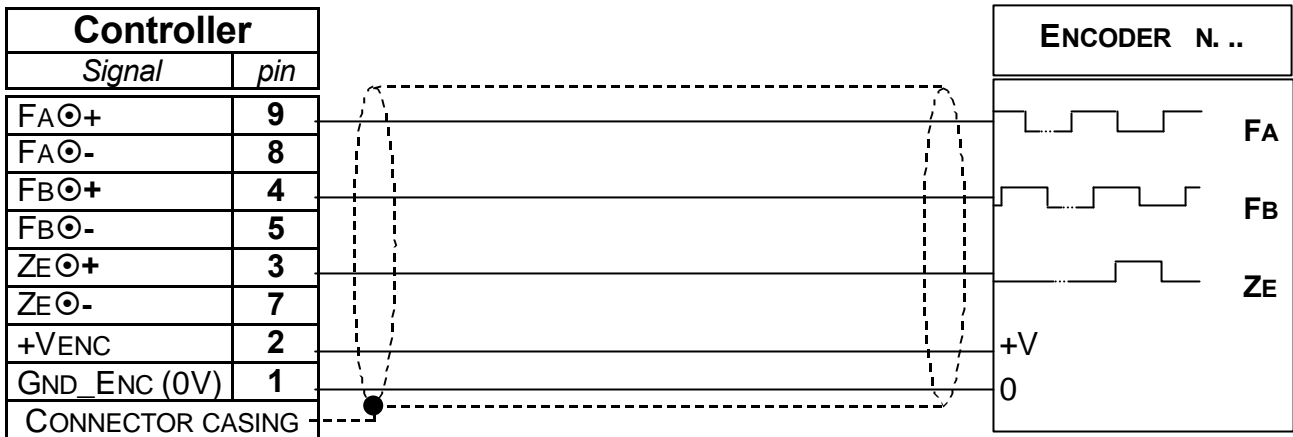


Fig. 3: Connections for unipolar encoder using internal power supply.

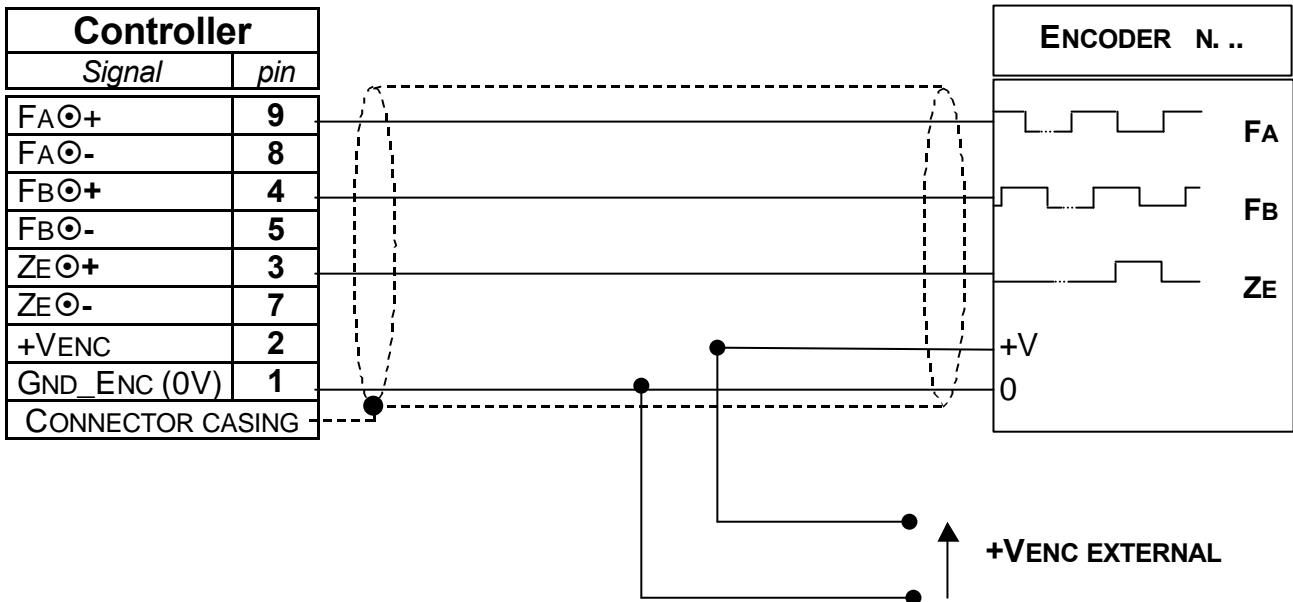


Fig. 4: Connections for unipolar encoder using external power supply.

## SOFTWARE CONFIGURATION

The purpose of the configuration of the controller software is to supply it with the necessary information to interpret the signals supplied from the system in the correct manner. To this end @ instructions are used. The software can be configured using the display and keypad of the controller itself, or using the Bach software package on any S&h controller.

When Bach software is available, access to all the parameters is facilitated by the data entry menus. The @ code that corresponds to the parameter on which the cursor rests will be seen in the hint-box (the yellow suggestion flag that appears when the cursor is allowed to remain stationary over an active area) of the parameter concerned.

If a controller interface is used, or a terminal, when programming the parameters, remember that it is possible to check what the controller has received with the % series of codes. For example, with the string “@16X1”, a value is assigned to the count direction of the X-axis. The string “%16” will obtain the reply “X1Y axes, from which it is seen that the instruction “@16X1” has been received and executed correctly.

**Important:**

To avoid damage to property and injury to persons, check that the parameters have been entered correctly with the motor drive units disabled and manually moving the encoder shafts. If for any reason this is not possible, see whether it is possible to disconnect the motor from the devices that it moves. If neither of these is possible, take great care that no damage can be caused by unexpected and uncontrolled movements of the motors.

For more information on the instructions, refer to the CNC programming manual.

**SETTING PARAMETERS**

For simplicity, all examples of strings given in these descriptions refer to the X-axis. It is take as given that identical considerations and identical syntax is valid for all the axes present. It is possible to specify the value of any parameter for each axis singularly or for more than one axis. For example, the string “@16X1Y0Z2W1” specifies the parameter @16 for all four axes.

The procedure indicated here does not consider the correspondence between engineering units and motor pulses. For the definition of these parameters, refer to the appendix that regards the calculation and settings of the axes’ parameters.

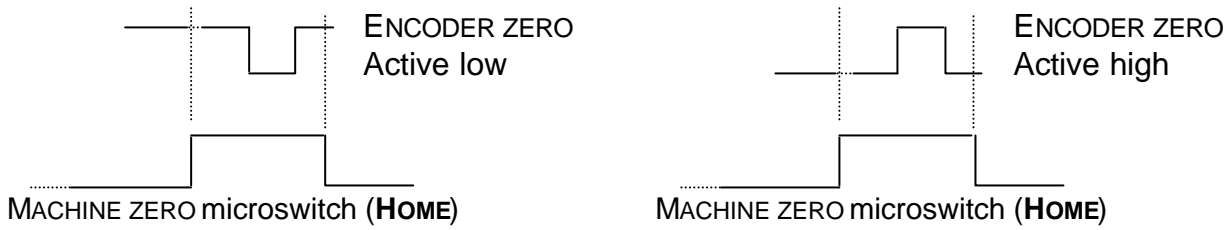
**@16:** Define the direction of the co-ordinate count.

If, after connecting the phase signals of the transducer to the CNC, the direction of the count is not correct, i.e. moving the axis forward, the co-ordinate decrements and viceversa, it is possible, using the function @16, to invert the internal count direction of the co-ordinates without physically inverting the connections of the phase signals to the controller, as illustrated in the next table.

Parameter	Effect
@16X0	Normal count
@16X1	Inverted count

**@15:** Define the encoder zero input

The parameter defines for the controller if the “encoder in zero position” corresponds to the state 1 or state 0 of the relative input. This signal is used together with the “HOME” input, during the machine zero search.



**Fig. 5: Waveform during the zero seeking.**

The following table shows the use of the parameter relative to the encoder function

Encoder signal	Parameter
Active low	@15X0
Active high	@15X1

For more information of the “machine zero” procedure, refer to the appendix regarding the setting of the axes’ parameters.

### **CHECK**

#### **@15:** Define encoder zero input

To check the correct setting of this parameter, refer to the machine zero programming inside the appendix that regards the setting of the axes’ parameters.

#### **@16:** Define the co-ordinate count direction

Move the encoder or the axis manually or by programming a movement in open loop and check that the count of the co-ordinate agrees with the direction of movement. If it is not, invert the value programmed for his parameter.

# CNC – APPENDIX F:

## CALIBRATING THE AXES

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## GENERAL

This appendix describes the operations to be followed to obtain the best possible operation of the controlled axes. It examines the parameters that influence the way an axis functions and gives indications for finding their most suitable values. Finally, the procedure to test the actual system performance is described. The operations described must be repeated for each axis used in the application.

Before beginning to calibrate the axes, it is necessary to have completed the electrical connections to the various components and to have programmed and checked the drive parameters. For details on how to do this, refer to Appendix D – MOTOR DRIVE INSTALLATION.

The parameters are programmed by sending a series of @ instructions, followed by a string of characters. It can be done using the control panel of the controller itself, when fitted, or using a terminal connected by serial link, or using PC connected by serial link and running the Bach software package. In the Bach software access to all the parameters is facilitated by the appropriate data entry menus. The corresponding @ code of the parameter on which the cursor rests can be seen in the hint-box (the yellow suggestion flag that appears when the pointer remains stationary over an active field) relative to that parameter.

If the controller interface or programming terminal is used for the parameters, remember that it is possible to check what the controller has received with the series of % codes. For example, with the string "@31X1" a value is assigned to the motor direction parameter of the X-axis. Using the string %31, the reply returns "X1Y..." for all the axes controlled, from which it is seen that the instruction "@31X1" has been received and executed correctly.

For simplicity, all the examples of strings that are shown in this description refer to the X-axis. It may be taken as granted that identical syntax is used for all the other axes present. For all other parameters, it is possible to specify the value for each axis separately or for more than one axis. For example, the string "@31X1Y0Z2W1" specific to the parameter @31 for all four axes.

The S&h controllers can be used with three types of controlled axes.

- Frequency controlled axis with open loop position
- Frequency controlled axis with encoder position feedback
- Voltage controlled axis with encoder position feedback

Some of the parameters to program are different in the different cases. Each section indicates to which type of axis it is referring.



## **DISABLING THE FEEDBACK LOOP**

### **ALL TYPES OF AXIS**

The instruction “@40X0” tells the X-axis that the movements are to take place in open loop. In this way, the controller will consider the actual co-ordinate to be the same as the theoretical co-ordinate. This parameter should not be changed until indicated differently.

## **DEFINING THE ACTIVE STATE OF THE LIMIT SWITCH INPUTS**

### **ALL TYPES OF AXIS**

For each axis, the controller can handle up to four inputs with predefined (dedicated) functions. These are:

- Fault
- Limit Switch +
- Limit Switch –
- Home

Of these, “Fault” is the only one to be physically different from the generic inputs and to which no other function can be associated as a programmable input. This choice is due to the consideration that it is not always necessary to use the limit switch inputs or the Home input. When these lines are not used for their specific function, they can be used as generic inputs, to which can be associated a series of standard functions. The users’ manual of the chosen controller is needed to identify the dedicated inputs on the controller’s connector.

The modes of programming the “Fault” input are described in the appendix regarding the connection of the motor drives. The modes for the other three inputs are described here.

Great care is recommended when using these inputs. In order not to penalise the flexibility of the controller, no limit has been placed on the possibility to associate different functions simultaneously to the same input. However, this does not guarantee that the functions to which they are associated can always actually be executed. If for example, on the Goya controller, input 9 is defined as active high for the forward limit switch on the X-axis, and simultaneously it is associated with the launch of a program. If the program begins with a displacement forwards of the X-axis, each time that it tries to execute the program, reacting on the push-button connected to input 9, the controller will go into emergency. This will not happen if the program does not move the X-axis straightaway or if it does move it straightaway, but in the opposite direction.

The controller will go into emergency on reaching a limit switch only if the axis is moving in the direction of that limit switch. It implies a non-recoverable stop to the program being executed, the loss of the machine zero reference and the disabling of the motor drive. To return to normal operation, it will be necessary to release the limit switch, re-perform the machine zero procedure and run the program again from the beginning. Any attempt to move the axis in the direction of the limit switch while this is active will reset the emergency.

Instructions @3 and @4 can be used to define the state of the line that causes the emergency according to the following tables. If the value of 2 is entered for the parameter, the input is disabled as a limit switch and it can be freely used as a generic input.

### **Limit switch forward**

Parameter	Line status	Controller status
@3X0	Open contact	Emergency
@3X0	Closed contact	-
@3X1	Open contact	-
@3X1	Closed contact	Emergency
@3X2	Indifferent	-

### **Limit switch backward**

Parameter	Line status	Controller status
@4X0	Open contact	Emergency
@4X0	Closed contact	-
@4X1	Open contact	-
@4X1	Closed contact	Emergency
@4X2	Indifferent	-

### **Checking the function of the limit switches**

To check that the limit switches are working correctly, simply program or execute a displacement manually towards the positive direction. While the axis is moving, activate the limit switch forward manually. If correct, this action will cause the drive to go into emergency. Reset the emergency and move the axis slowly in the negative direction. While moving activate the limit switch backward, checking that the axis goes into emergency for this motive.

## **DEFINING THE ACTIVE STATES OF THE ZERO INPUTS**

### **FREQUENCY CONTROLLED AXES IN OPEN LOOP**

The purpose of the zero (Home) input is to enable the controller to recognise the zero position of the axis. During the machine zero seeking procedure, this input assumes the state defined as active. The controller assumes the current step of the motor to be the absolute zero position. In a similar way to the limit switches, the active state can be defined with its specific parameter.

Parameter	Line status	Controller status
@6X0	Open contact	Machine zero
@6X0	Closed contact	-
@6X1	Open contact	-
@6X1	Closed contact	Machine zero
@6X2	Indifferent	-

**Checking the function of the zero input**

To check that the zero input is working correctly, simply move the axis to a position in which the zero sensor is not active, program the controller to perform a machine zero seeking procedure (instruction “G51X-F100” to execute the zero seeking on the X-axis, in the negative direction at a velocity of 100mm/second) and check that the axis stops as soon as the sensor is activated. If the active state has been programmed wrongly, the axis will not even move. If the input is not enabled, the axis will not stop when the zero sensor is active and it will be necessary to stop the axis with an emergency manual instruction.

**AXES WITH ENCODER FEEDBACK**

The purpose of the Home input is to enable the controller to recognise the portion of the travel in which the position of the axis zero is found. During the zero seeking procedure, this input assumes the state defined as active and the controller enables the input of the encoder zero signal. When this becomes active, the controller assumes the current value of the encoder pulse counter as the absolute zero position. In a similar way to the limit switch inputs, the active state can be defined with its specific parameter.

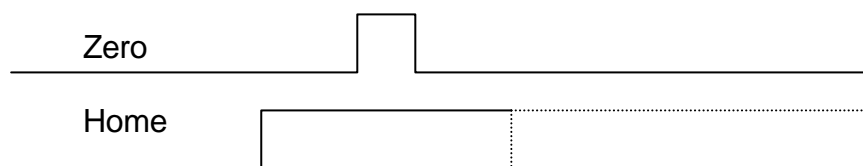
Parameter	Line status	Controller status
@6X0	Open contact	Machine zero
@6X0	Closed contact	-
@6X1	Open contact	-
@6X1	Closed contact	Machine zero
@6X2	Indifferent	-

Also the zero signal generated by the encoder can be active high or active low, depending on how the connections have been made.

Parameter	Controller status
@15X0	Encoder zero active low
@15X1	Encoder zero active high

The optimum operational conditions are found when the encoder generates the zero pulse after having made a half turn after the system has operated the zero sensor. In this event, there will never be any uncertainty of the acquired position. If the zero sensor is activated for a length of track that is smaller than that which corresponds to one revolution of the encoder, the zero signal needs to be present half way down the stretch in which the zero sensor is active. To obtain this result, it will be necessary to adjust the relative positions of the mechanical parts, the motor and the encoder.

If an oscilloscope is available, the set-up procedure is very much easier. It is sufficient to ensure that the zero pulse from the encoder falls at the centre of the zero sensor pulse, as illustrated in the figure, and then invert the programming of the active states if necessary to obtain the correct operation.



**Fig. 1: Drawing of the states of the signals at the machine zero.**

If an oscilloscope is not available, to check that the Home input is working correctly, it is necessary to:

1. Move the axis far away from the position in which the zero sensor is active,
  2. Program the zero seeking on the axis (instruction "G51X-F100" to perform a zero seeking on the X-axis in the negative direction at a velocity of 100 mm/second),
  3. Wait until the motor has completed one complete revolution,
- If the active state has been programmed wrongly, the axis will stop before the motor has completed a revolution or it will not even start to move.

4. Manually activate and hold the zero sensor,
  5. Check that the motor stops within one revolution from this moment.
- If the input is not enabled, the axis will not even stop within the one revolution from when the zero sensor is operated and it will be necessary to stop it with a manual emergency instruction.

To check that the encoder zero signal is working correctly, it is necessary to:

6. Move the axis to a position where the zero sensor is not activated.
7. (instruction "G51X-F100" to perform a zero seeking on the X-axis in the negative direction at a velocity of 100 mm/second),
8. check that the axis stops as soon as the zero sensor is activated.

If the axis stops after moving a short way after activating the zero sensor, the active states have been programmed correctly and the only job to do is to adjust the exact phase between the encoder and the mechanical parts (part 12 of this procedure). If, on the other hand, the axis stops immediately the zero sensor is activated,

9. invert the parameter using @15 (indicate X0, if it was previously X1 or viceversa).

If the axis stops again immediately the zero sensor is activated,

10. loosen the fixing of the encoder body and rotate it 180° with respect to its previous position.

If the axis stops again immediately the zero sensor is activated,

11. invert the parameter again using @15 (indicate X0, if it was previously X1 or viceversa).

At this point, the axis must travel a short distance before stopping after activating the zero sensor.

12. Adjust the angular position between the encoder and the mechanical parts such that the zero point falls in the middle of the tract in which the zero sensor is activated, or, if the sensor is at one end of this tract, that the zero point falls a half turn after the zero sensor has been activated.

## **DEFINING THE DIRECTION OF THE CO-ORDINATE COUNT**

### **AXES WITH ENCODER FEEDBACK**

The @16 instruction can be used to specify the count direction of the encoder pulses, so that it agrees with the co-ordinates and positions of the axis. To check how the controller is working when the encoder is moved, move the axis by hand in one direction and check whether the actual co-ordinate moves in the right direction. If it is not correct, (the co-ordinate decreases when it should increase or viceversa) the parameter must be changed.

Parameter	Controller status
@16X0	Normal count
@16X1	inverted count

Since the count can be inverted also by swapping the positions of the two wires of a single phase encoder, it is necessary to check the count direction every time the encoder wires are disconnected from the connectors or the encoder is replaced.

**Always check that the frequency that is generated at the maximum velocity does not exceed the maximum frequency that the controller can read and that is specified in the technical specifications of the users' manual of the chosen controller.**

## **DEFINING THE ENGINEERING UNITS/PULSES RATIO**

### **POSITION CONTROLLED AXES**

The @51 instruction is used to define the correspondence between the displacement of the axis and the number of steps of the motor to which the displacement corresponds. For example, if the motor has 400 steps/revolution and it drives a screw with a pitch of 4mm, 400 steps corresponds to 4mm of displacement. In these conditions, the ratio can be expressed with the following instructions, all of which will have the same effect.

“@51X1,100” or “@51X4,400” or “@51X16,1600”

where the first of the two values is the displacement of the axis, the second is the number of steps of the motor required to obtain it. Both values must be different from zero. If there is a gear reduction between the motor and the moved device, this must be taken into account when making the calculation.

If a system with telekinetic transmission by belt with a pulley of 100mm diameter, driven by a stepper motor with a gear ratio of 1/6 and a motor of 800 steps/revolution, 4800 steps will be needed to make a complete revolution of the pulley, which will cause a linear displacement of 100mm. The parameter can therefore be specified as:

“@51X100,4800” or @51X1,48”

which specifies that a millimetre corresponds to 40 encoder pulses. There are also cases in which the resolution is expressed by numbers with recurring decimals. For example, if an encoder with 300 notches is fixed to a screw with a pitch of 5mm, the value of the resolution R would be 0.00416, with a recurring 6. In this case, programming the parameter as “@50X0.0041666,1” will cause rounding errors. It is therefore obligatory to use the expression “@50X5

Remember that all S&h controllers internally multiply the number of encoder pulses by 4. In the previous example, note that the screw pitch does not change, while the number of notches on the encoder is multiplied by 4 to obtain the correct number of encoder pulses for a complete revolution.

Every motor has its maximum speed of rotation (typically 2000 or 3000 r.p.m.), to which there will be a corresponding absolute maximum pulse frequency that the encoder can generate. This data is used to inform the controller of the parameter  $\Delta f/\text{time}$  that characterises the acceleration and deceleration ramps.

For example, a motor of 3000RPM max, with an encoder of 400 notches fixed directly on the shaft, the maximum frequency is calculated according to the following formula:

$$f_{\text{MAX}} = \frac{\omega_{\text{MAX}}}{60} \times 4 \times N/\text{rev.} = \frac{3000}{60} \times 4 \times 400 = 80000 \text{ Hz, where: } \begin{array}{l} f_{\text{MAX}} = \text{max. frequency} \\ \omega_{\text{MAX}} = \text{max. velocity} \\ N = \text{number of notches} \end{array}$$

The factor of 4 takes into account the factor of 4 by which the controller multiplies the number of encoder pulses at the input, while the constant 60 compensates for the difference between the measurement units of  $\omega_{\text{MAX}}$  (expressed in rpm/second) and  $f_{\text{MAX}}$  (expressed in cycles/second).

**Always check that the frequency generated at the maximum velocity does not exceed the maximum frequency that the controller can handle and that is stated in the technical specifications of the users' manual of the chosen controller.**

The instruction “@53X80000” specifies to the controller that the frequency at maximum velocity is 80,000Hz.

## **DEFINING AND LIMITING THE MAXIMUM FREQUENCY THAT IS SENT TO THE MOTOR DRIVE**

### **AXES WHERE THE POSITION IS FREQUENCY CONTROLLED**

Every stepper motor has its maximum rotation speed, and a corresponding absolute maximum frequency at which it can be driven. If this limit is exceeded, the motor will effectively stop and not execute the requested displacement. It is therefore necessary to prevent the controller from generating too high a frequency.

For example, a motor with 800 steps/rev., maximum 1000 RPM, the maximum frequency is calculated using the following formula:

$$f_{\text{MAX}} = \frac{\omega_{\text{MAX}}}{60} \times \text{S/rev.} = \frac{1000}{60} \times 800 \cong 13333 \text{ Hz, where}$$

$f_{\text{MAX}}$  = max.frequency  
 $\omega_{\text{MAX}}$  = max.velocity  
 S/rev. = steps/rpm of the motor

**Always check that the frequency that must be sent to the motor to obtain the maximum velocity is not higher than the maximum frequency that the controller can generate and that is stated in the technical specifications in the users' manual of the chosen controller.**

The instruction “@53X13333” is used to specify to the controller that the maximum velocity of the motor corresponds to 13333Hz. This data is needed to calculate the variation of frequency during the acceleration and deceleration ramps.

The frequency generated can be limited with the instruction “@84,1”, that enables the velocity to be limited on all the axes present. After sending this instruction, in no event can it generate a frequency higher than 13333Hz on the X-axis.

### **AXES WHERE THE VELOCITY IS FREQUENCY CONTROLLED**

The frequency data that determines the maximum velocity of the motor is stated in the motor drive's documentation. If the maximum frequency is, for example, 100,000Hz, simply give the instruction “@53X100000”.

**Always check that the frequency that must be sent to the motor to obtain the maximum velocity is not higher than the maximum frequency that the controller can generate and that is stated in the technical specifications in the users' manual of the chosen controller.**

## **DEFINING THE NUMBER OF DECIMALS USED**

### **ALL TYPES OF AXIS**

The function @71 can be used to define the format of the data that is sent by the controller in reply to any request to read its internal data. It is used to indicate the number of digits after the decimal point and it must be an integer between 0 and 5.

The string "@71X3" fixes the number of decimals on the X-axis at three, and it also affects the expression of the data contained in the variables transmitted in reply to the %81 code (refer to the programming manual for greater detail), that will be transmitted in the same format as that assigned to the X-axis.

## **DEFINING THE AMOUNT OF FEEDFORWARD**

### **POSITION CONTROLLED AXES**

When frequency driven motors are used, the parameter "@46X100" must be sent to the controller so that the amount of feedforward is not varied. The feedforward is the frequency that the controller produces in open loop as a function of the required motor speed.

### **VELOCITY CONTROLLED AXES**

In some cases it is useful if the feedback loop always gives a contribution to the analogue output voltage, as this improves the system's stability. The controller calculates the voltage to generate by taking the required velocity on the basis of the maximum frequency that the encoder can generate and the correspondence between the encoder pulses and linear displacement in engineering units. Doing this, the controller obtains an ideal value for the voltage due to feedforward that can be reduced by assigning the parameter @46 a value less than 100. The data must be an integer between 1 and 100.

$$FF_O = \frac{K_{ff}}{100} \times FF_T \text{ where}$$

FF<sub>O</sub> = Actual value of the feedforward contribution  
 FF<sub>T</sub> = Ideal value calculated by the controller  
 K<sub>ff</sub> = Value assigned to parameter @46



## **DEFINING THE START AND STOP VELOCITIES**

### **FREQUENCY CONTROLLED AXES**

Stepper motors have the possibility of starting with an “instantaneous” velocity that is indicated by the manufacturer as the maximum start and stop frequency for the motor in integer steps (200 steps/rev.) This prerogative is used to make the movements as rapid as possible and to avoid the very low frequency regime in which the resonant frequency of the motor is typically found. Remember that the start and stop frequency is multiplied by 2 if the motor functions by ½ steps and by 4 if it functions by ¼ steps and that the value of frequency must be an integer value.

The instruction “@56X150” specifies that the X-axis, when put into movement by a G0 instruction, immediately goes to the velocity that corresponds to the frequency of 150Hz, and then accelerates up to the velocity specified with the F code. When it stops, it decelerates down to a frequency of 150Hz and then stops.

During interpolated movements, the start and stop velocities are calculated on the basis of the slowest axes among those involved in the movement.

## **DEFINING THE DURATION OF THE ACCELAERATION RAMP**

### **ALL TYPES OF AXIS**

The time required to reach the maximum velocity, starting from the start velocity, depends substantially only on the mass that the motor must accelerate. If this can change from time to time, for example if the system moves a load in one direction and then returns empty, the acceleration ramp must be programmed to allow the system to work in the most difficult conditions. There is nothing to stop the value inside the program being dynamically modified in order to take full advantage of the systems potential performance.

The parameter’s data is an integer value in milliseconds in the range 0 to 9999 (9.999 seconds). The instruction “@57X1000” indicates that the X-axis takes one second to reach the maximum velocity starting from rest.

In some cases, the maximum linear acceleration that the system can handle, expressed in **g**, is used. In this case, to find the theoretical value of the acceleration ramp time in milliseconds, the following formula can be used:

$$T_{\text{Ramp}} = \frac{R \times f_{\text{MAX}}}{9.8 \times a_g} \times 1000$$

where R is the resolution expressed in metres,  $f_{\text{MAX}}$  is the maximum frequency that may be sent to the motor,  $a_g$  is the data for the acceleration expressed in **g**. For example, if a system must be actuated by a motor with 400 steps/rev. and a maximum frequency of 8000Hz, that drives a screw of 6mm pitch, and which can support a linear acceleration of 0.2g, the resolution R (see Appendix C – CHOICE OF ENCODER) is 0.015, equivalent to 0.000015 metres and therefore

$$T_{\text{Ramp}} = \frac{R \times f_{\text{MAX}}}{9.8 \times a_g} \times 1000 = \frac{0.000015 \times 8000}{9.8 \times 0.2} \times 1000 = \frac{15 \times 8}{1.96} \cong 61.224 \text{ ms}$$

If the value of the acceleration is expressed in  $\text{m/s}^2$ , the formula becomes

$$T_{\text{Ramp}} = \frac{R \times f_{\text{MAX}}}{a_{\text{m/s}^2}} \times 1000$$

If no data is available for the maximum acceleration, it is necessary to ascertain it with a different empirical procedure for each type of axis, as described in the following.

### **POSITION CONTROLLED AXES**

If the time assigned to the acceleration ramp is too low, the motor stops, or at least completely loses its position. It is this very feature that enables the minimum value that can be assigned to this parameter to be found.

Starting from an arbitrary high value, come down, for example 1000 by 1000, until the axis stops. Then go back one step and come down again 100 by 100 and so on, as illustrated in the following example.

```
@57X5000
G0X2000F100000
    Displacement executed
@57X4000
G0X0F100000
    Displacement executed
@57X3000
G0X2000F100000
    Displacement executed
@57X2000
G0X0F100000
    Displacement executed
@57X1000
G0X2000F100000
    Motor stopped
@57X1900
G0X2000F100000
    Displacement executed
@57X1800
G0X0F100000
    Displacement executed
@57X1700
G0X2000F100000
    Displacement executed
@57X1600
G0X0F100000
    Motor stopped
```

@57X1690  
G0X0F100000

Displacement executed

And so on until the lowest speed at which the motor does not stop is found. **Before performing this procedure, ensure that the velocity limit has been enabled with the instruction @84,1.** The value found in this way must then be increased by 10% as a precaution against the degrading of the motor, loss of torque due to high working temperatures and other conditions that could in some way reduce the efficiency of the system.

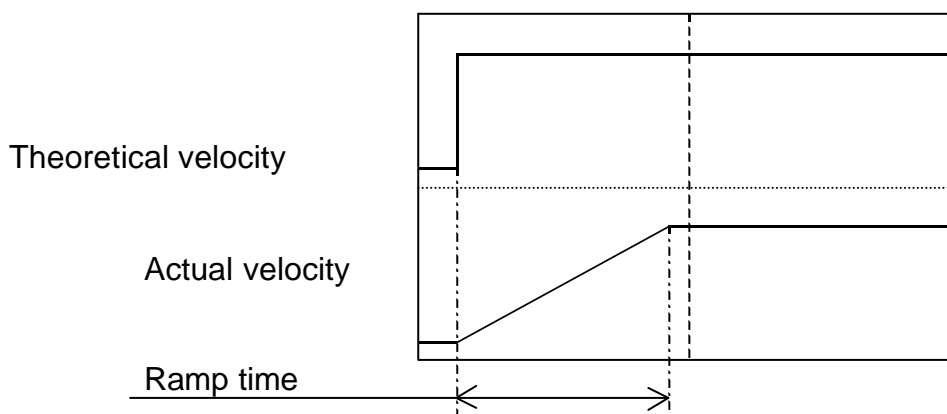
### VELOCITY CONTROLLED AXES

To establish the time to assign to the ramp for this type of axis, it is necessary to obtain an oscilloscope with memory so that it is possible to store the behaviour of the voltage generated by the dynamo, if fitted, under control, or, the speed signal if the motor drive has an analogue output with voltage proportional to the motor speed. If neither of these two signals is available, a frequency-voltage converter is needed, the input of which is connected to the signal from one phase of the encoder.

All these difficulties are overcome if the BACH program is available. By recording the movements, it is possible to see and to measure the behaviour of the actual position of the axis directly, instant by instant.

Whatever method is used, the procedure is identical. Remember that the parameter @40 must still be programmed to the value 0.

1. Program the parameter “@57X2047” so that the controller can generate a step that carries the speed from 0 to maximum without an acceleration ramp.
2. Make a movement at the maximum velocity. The movement must be long enough for the axis to reach its maximum velocity.
3. Measure the time in milliseconds (on the oscilloscope or Bach) for which the axis remains in acceleration.
4. Increase this value by at least 10%.
5. Reprogram the parameter @57 with this value.



**Fig. 2: Plot of the duration of the ramp during acceleration.**

## **DEFINING THE PARAMETERS OF THE FEEDBACK LOOP**

### **POSITION CONTROLLED AXES IN FREQUENCY WITH ENCODER FEEDBACK**

In this case, it is necessary to put all the gain parameters of the various elements of the loop to 0 (@43X0, @44X0, @47X0, @48X0, @49X0), except @42X16 (recommended and default value) and assign some value to the sampling time of the derivative signal (@49x1)

The only critical value is @40, whose value, in engineering units, must correspond to the maximum error tolerated under the worst conditions (for example “@40X1”, if an error of plus or minus one millimetre is acceptable for the position of the axis, with respect to the theoretical position). Check experimentally then that it does not generate unjustified emergencies: if so it will be necessary to increase the system tolerance by increasing the value assigned to @40.

### **VELOCITY CONTROLLED AXES**

In this type of axis, the control feedback loop has the purpose of ensuring the correct position of the static and dynamic position and therefore the tuning of the parameters is of fundamental importance for the accuracy of the machine. Remember that, if the feedback is obtained from the subsequent movement of mechanical parts (for example from an optical ruler moved by the trolley of a slide) the control loop must also compensate for errors due to mechanical play. In this case, the tuning of these parameters could be even more critical.

In all S&h controllers, the output signal is the algebraic sum of four terms, “feedforward”, proportional correction, derivative correction and integral correction, calculated according to the following principles:

- Open loop gain (“feedforward”): the component proportional to the desired setpoint that is present even in the case of perfect coincidence (actual and historical) between the theoretical position and the actual position ( $\varepsilon = 0 \wedge d\varepsilon / dt = 0 \wedge \int \varepsilon dt = 0$ ),
- Dead band: the maximum error between the actual position and the theoretical position that is ignored by the feedback loop,
- First proportional gain: the component proportional to the instantaneous error that manifests itself up to a maximum error defined by the user, the so-called “knee point”,
- Second proportional gain: the component proportional to the instantaneous error that manifests itself beyond the “knee point”,
- Derivative gain: the component proportional to the difference between the current error and the previous error averaged over a time defined by the user, the so-called “sampling time”,
- Integral gain: the component proportional to the algebraic sum of all the errors verified during the operation. This component has a limit in absolute value, the so-called “integral limit” that is defined by the user.

One last parameter, added at the discretion of the user, is the maximum error within which the controller will try to recover, the so-called “servo error limit”. For instantaneous errors greater than this level, the controller no longer performs its task and places itself in emergency.

The whole control system, including the PID algorithm can be graphically illustrated by the following figure:

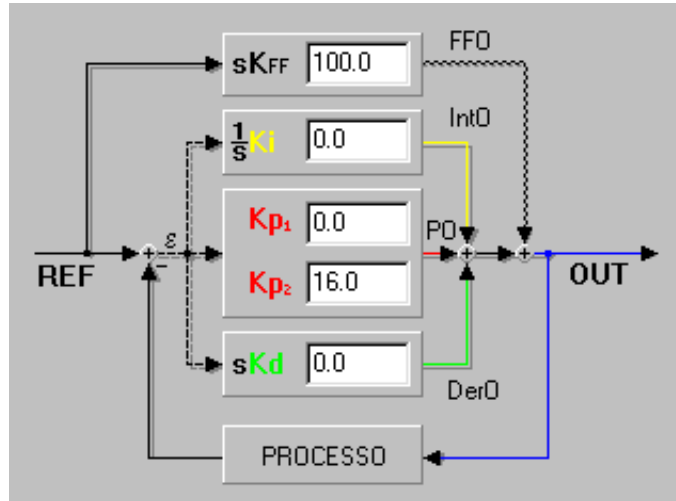


Fig. 3: Functional diagram of the feedforward and the control loop.

### Setting the proportional gain

The proportional gain works so that the controller makes a correction to the frequency of the signal sent to the motor drive that is proportional to the instantaneous difference between the actual position and the theoretical position. If the gain is too small, accuracy is lost, especially during movements, if it is too high, the motor speed will oscillate, as it cannot follow the acceleration time that the controller is asking for.

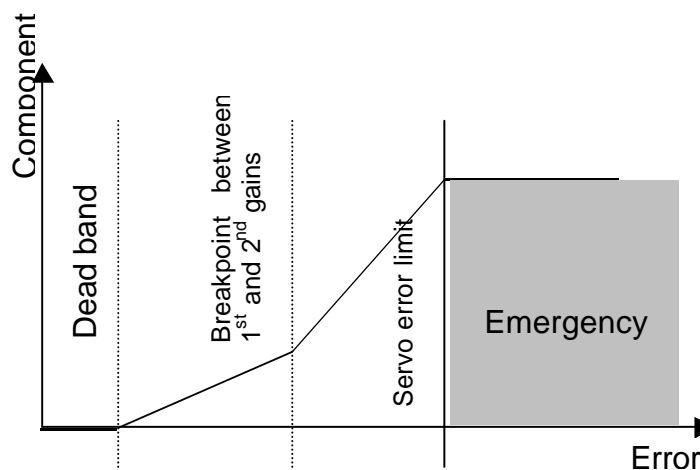


Fig. 4: Behaviour of the proportional component

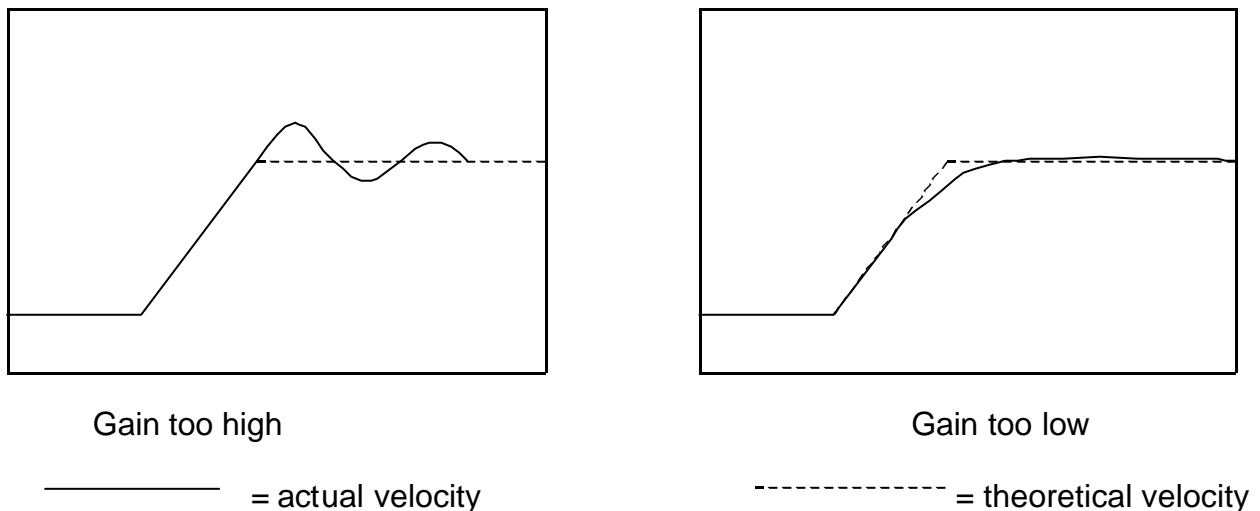
S&h controllers have two values for the proportional gain, a band around the null error position in which the proportional term is zero and a breakpoint of the absolute error above which the second proportional gain is operative, as shown in figure 4.

In the large majority of applications, the dead band and first proportional gain are not needed and they are disabled by assigning a value of zero to the relative parameters (@41X0 disables the dead band for the X-axis and @49X0 disables the first proportional gain).

The dead band can be useful when an encoder must be used that has a better resolution than the stepper motor employed. Setting a suitable value for this parameter, it avoids that the motor continues to oscillate around the position at which it should stay at rest.

The two values of proportional gain can be used in particular applications. For example, in a system that must move significant weights, the axes will have low acceleration due to the inertia. In this event, it could be necessary to use a very low gain to avoid oscillations. However, this would excessively compromise the accuracy of the positioning. In this situation, the best result is obtained by setting the first gain at a high value to ensure small errors in positioning and as the error increases, the second gain will come into play and with a very low value to avoid oscillation during the movements.

As an example, the two figures below show the difference in theoretical behaviour and the actual velocity during and immediately after the acceleration ramp in the first case with a proportional gain that is too high and the second, when it is too low.



**Fig. 5: Dynamic errors in positioning induced by the wrong proportional gain.**

To optimise the value of the proportional gain (@42X...) it is necessary to exclude the intervention of the other terms (@43X0 and @44X0), then starting at low values, increase the gain until smooth oscillations are seen around the velocity at regime (the axis will go over the theoretical value and then slow down too much, then reaccelerate etc.). At this point, reduce the value by 50% to give a reasonable margin of stability. Once the gain values are optimised, they must not be changed again, or reset to zero when proceeding to the optimising the other terms.

Remember that the range of values allowed for all the gain parameters is from 0 to 2047 and that the feedback loop must be enabled by assigning the limit (@40) a value different to 0 and possibly higher than the final accuracy that you intend to obtain in order to avoid that the system goes often into emergency.

The tuning of systems that require two values of proportional gain depend very much on the specific details of the application and possible solutions are not discussed in this appendix. The tuning of such systems must be analysed carefully and differently for each particular application.

### ***Tuning the integral term***

The integral term has is used to eliminate the effect of systematic errors, such as those due to an offset not being perfectly calibrated, or, in the case of axis with vertical movement, the effect of the gravitational load on the controlled system. In any case, it is better not to exaggerate the value set for the integral gain (@43). Set a low limit (for example 200, corresponding to approximately a tenth of the maximum speed) for the maximum effect of this (@47) and check carefully that there is no oscillation either of speed or of position.

### ***Tuning the derivative term***

The job of the derivative term (@44) is to add a correction that takes into account the variation of the error in time. Since the effect is to diminish the severity of the correction made to reduce the value of instantaneous error, in many cases it contributes to improve the stability of the system. Remember that the sampling time (@45) must be longer when the response of the system is slower. Check very carefully that the enabling of this term does not worsen the accuracy and the stability of the system.

## **CHECKING THE CORRESPONDENCE BETWEEN DISPLACEMENT AND CO-ORDINATES**

### ***OPEN LOOP, FREQUENCY CONTROLLED AXES***

To check the correspondence between the displacement and the motor pulses, simply make a measurement between a fixed and a moving part of the system in the direction of movement, make displacement of known distance on the axis (for example G0X+100F200 to move the X-axis 100mm forward from its present position at a velocity of 200mm/second), measure the distance again between the same two parts and check that the difference corresponds to the programmed movement.

### ***AXES WITH ENCODER FEEDBACK***

To check the correspondence between the displacement and the entered co-ordinates, it is necessary to:

- Take note of the actual position of the axis (^),
- Measure the distance in the direction of movement between a fixed part and a moving part of the system,

- Make a known movement with the axis, for example G0X+100F200 to move the X-axis forward 100mm from its present position at a velocity of 200mm/second.
- Measure the distance between the same two parts again
- Check that the difference between the two measurements corresponds to the programmed movement.

## ***SAVING THE PARAMETERS***

### ***ALL TYPES OF AXIS***

The parameters are saved to an area of the memory that is volatile, so its contents will be lost when the controller is switched off. The instruction @99 copies all the values entered into the internal permanent (flash) memory and they will be reloaded each time the controller is powered up.



# **Cnc – APPENDIX G:**

## **COMMANDS AND SETTINGS FOR LASER CONTROL**

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**APPENDIX VERSION: 1.1**

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**MANUAL CODE: MA CNC U APPG 11**

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DATE 20/07/02

## INTRODUCTION

The present appendix describes how to connect a laser system to S&h controls (Goya, Picasso and Rubens) and which commands are to be used for controlling the laser.

Two different modes are available for controlling the laser:

- analog
- through PWM (*Pulse Width Modulation*)

*In this appendix, only the PWM mode will be described.*

In both cases, the task is to adjust the laser power. In the simplest analog mode, the laser power is proportional to the voltage supplied by the control. For instance, the voltage may vary from 0 to 10 V, so that 0 V corresponds to no power and 10 V corresponds to 100% power. Of course, more complex laser exist, where the voltage-power relationship is not a linear one. In some cases also the maximum power may be achieved for a voltage different from the maximum one.

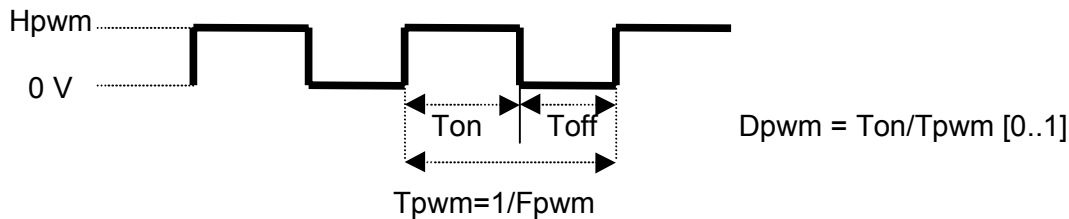
In the PWM mode, the control supplies a digital signal, which is characterised by the following features:

Fpwm: Frequency of the PWM signal

Tpwm: Period of the PWM signal (equal to  $1/F_{pwm}$ )

Dpwm: PWM Duty cycle: ratio between the time interval in which the signal is Hpwm volt (Ton) and the total signal period (Tpwm)

Hpwm: voltage when the PWM signal is high



The voltage Hpwm is supplied cyclically, according to a given period (Tpwm). The ratio between the time interval in which the voltage is supplied (Ton) and the overall cycle time (Tpwm) determines the effective laser power. This ratio is called *duty cycle*. For instance, if voltage is supplied for half period (and no voltage is supplied for the other half), the laser will work with 50% power.

The length of the period is related to the resolution; this is because the voltage control is linked to the *clock frequency* of the control, which is fixed. If the period is short, it will contain only few clock cycles, and the resolution will worsen. On the contrary, if the period is too long, even if the resolution is better, the laser power may become inconstant, due to a *ripple* effect.

On the control, suitable functions are available, in order to adjust Tpwm and the duty cycle: furthermore, it is possible to link the duty cycle to other quantities managed by the control, such as the axes' speed. In this way, the laser power on the piece to be worked can be kept constant, independently of the speed according to which the laser moves. In other words, it is possible to increase the laser power when the laser moves with higher speed and to decrease it when the laser moves with lower speed.

The law is a linear law, i.e.  $Dpwm = fLin(x)$  where *fLin* is chosen among the quantities that can be selected with the @52 command. The definition of *fLin* is done with the @52 command, by identifying setting two points P1,P2 in the Dpwm,x plane.

The output characteristic depends on the chosen control, and so also the controlling voltage Hpwm depends on the control. The presence of this function on the control is an *option* of the control itself.

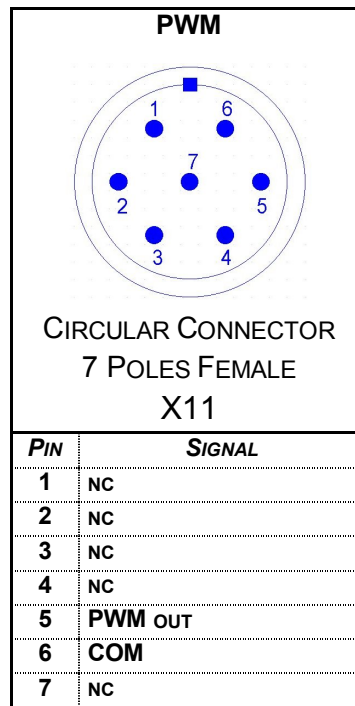
On the contrary, the commands for setting Tpwm and Dpwm are independent form the chosen control.

## CONNECTING SCHEME

The connecting scheme to be used depends of the hardware of the control. A first scheme applies to Goya and a second one applies to Rubens (6 axes) and Picasso.

### CONNECTING TO A GOYA

On the Goya a special connector is available for the PWM output. This output is of a TTL type. The connector scheme is shown in the following figure.

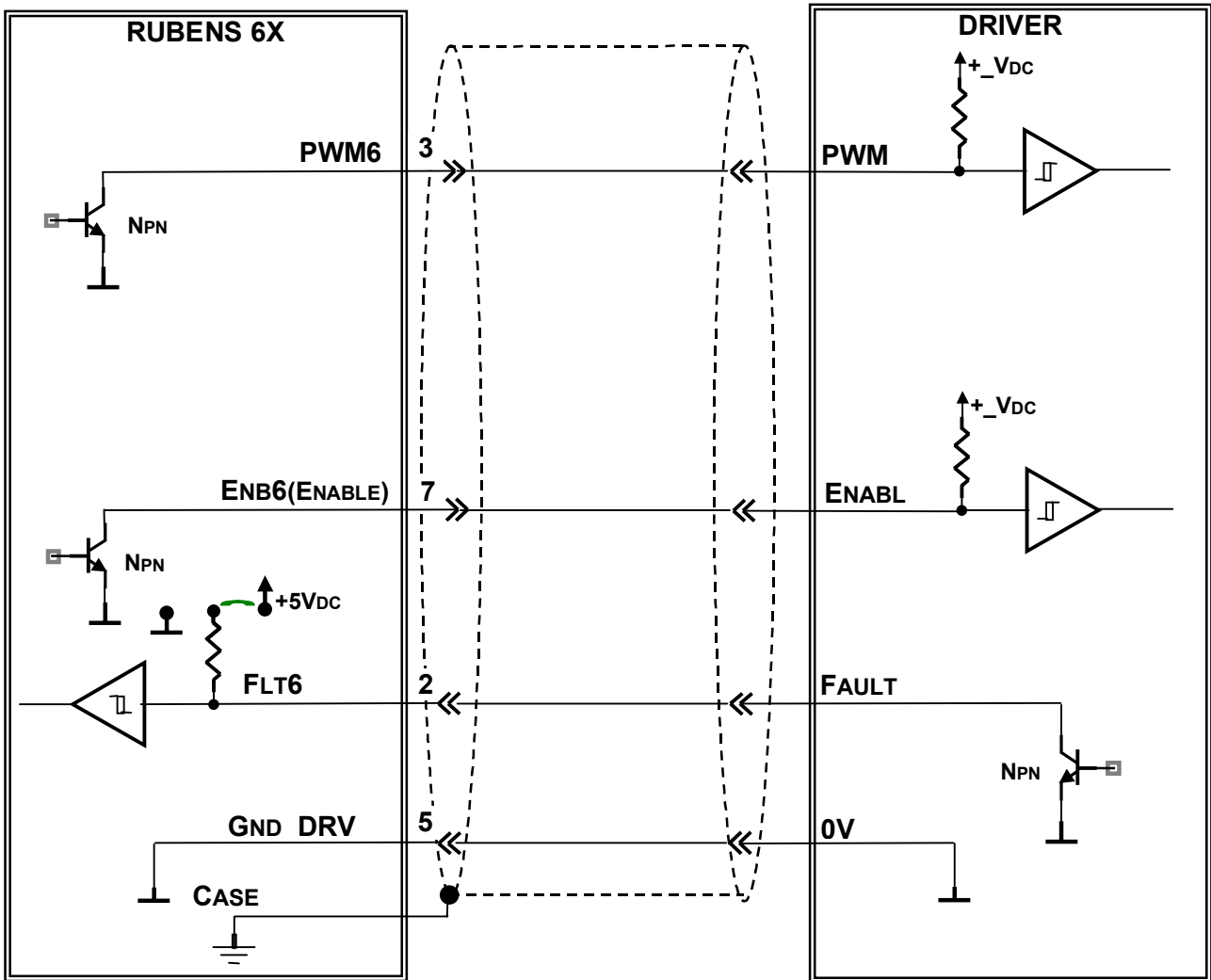


- PWM Out:** standard TTL signal
- COM:** reference ground PWMOut
- NC:** not connected (leave them unconnected)

### CONNECTING TO A RUBENS (6 AXES) OR A PICASSO

On Rubens and on the Picasso board no special connector is available for PWM; nevertheless, one of the standard (general purpose) digital outputs can be used as PWM output. In particular, the connector axis number 6 is to be used. This connector is identified by the label XD6.

The connecting scheme is shown in the following figure.



Comments: The cable shield must be connected to the connector case of the control.  
 It is possible to control the optoisolated inlets of the amplifier by means of the +5Vdc voltage which is available on pin 4 of the connector.  
 If the **DRIVER** has no internal pull-up resistors, the resistors must be provided externally.  
 The control frequency output, **PWM**, can be as high as 800 kHz with a 50% duty cycle.

## COMMANDS FOR LASER CONTROL

In the CNC programming language that is used by S&h controls, two specific commands are available for managing a PWM output:

- G68 H7
- @52

This section will describe these commands.

### @52 / %52 DEFINE ANALOG VOLTAGE RATIO

Pic2000	Goya	Rubens						
---------	------	--------	--	--	--	--	--	--

#### Properties

Source	Host computer / Resident program	
Active	In the block that is programmed	
Execution	Queued	
Conditions	-	
Compatible functions	-	
@ syntax	@52 (i)[(g2),(v2) [(g1),(v1)]] (i) : identifier (g1) : r.p.m. or speed of first point (default = 0) (v1) : associated voltage of first point (default = 0) (g2) : r.p.m. or speed of second point (v2) : associated voltage of second point	(*)
% syntax	%52	(*)
CNC reply	(i),(g2),(v2) [(g1),(v1)]	

(\*) The % command is used for reading parameters, the @ command is used for setting them.

#### Description

This function can be used to define the ratio between the axis speed or the r.p.m. of a spindle (g) and the voltage obtained at the output.

The identifying character (i) can have the following meanings:

' ' => disabled (default)

'S' => spindle (analog output enables from the instruction ISO S)

'X' => X-axis (analog output proportional to the X-axis speed)

'Y' => Y-axis (analog output proportional to the Y-axis speed)

'Z' => Z-axis (analog output proportional to the Z-axis speed)

'W' => W-axis (analog output proportional to the W-axis speed)

'I' => point speed in interpolation (analog output proportional to the interpolation speed)

Setting only one point defines a characteristic that passes through the zero (rotation speed or movement equal to zero has an output voltage of zero volts).

Setting both points (different from each other) defines a characteristic that do not pass through the zero (speed equals zero when the output voltage is different from zero).

Parameters v1,v2 identify an analog output voltage. If a PWM output is programmed, a correspondence is created between the duty cycle and the voltage:  $D_{pwm}[\%] = v \cdot 10$ .

For instance v=5 is equal to a 50% duty cycle.

e.g.: defining an analog voltage ratio

@52 S8000,10 ;with the instruction S800, there is an output voltage of 1 volt  
 @52 I0,-1.5 6000,0 ;in the interpolated movements with stationary axes, there is an output  
 ;voltage of -1.5 volt and a voltage of 0 volt at a speed F6000

e.g.: reading analog voltage ratio

%52 ;request to read analog voltage ratio  
 S8000,10 ;reply from controller  
 %52 ;request to read analog voltage ratio  
 I6000,5 1000,-2 ;reply from controller

<b>G68 HANDLING DEVICES</b>								
-----------------------------	--	--	--	--	--	--	--	--

Pic2000	Goya	Rubens						
---------	------	--------	--	--	--	--	--	--

**Properties**

Source	Host Computer / Resident program	
Active	In the block that is programmed	
Execution	Queued	
Conditions	-	
Compatible functions	-	
Syntax	G68 [H(n)(...)]	

**Description**

With the G68 command, some internal functions of the control can be activated or deactivated. Among the other functions (described in detail in the *CNC Programming Manual*), a function is available for controlling the PWM output, by means of the H7 parameter. The syntax is as follows.

**G68 H7, (NO), (PRESCALER), (BITR): MANAGING THE OPTIONAL DEVICE "PWM OUTPUT"**

enables and disables the PWM function on a logic output, defining the period and the resolution of the signal that will be generated. As to the regulation of the duty cycle, the output will be handled as an analog output, using the instructions for controlling the spindle: @52 for the CNC or handling analog outputs for the PLC.

NO specifies the number of the output. In the Goya, that has a dedicated connector for the PWM output, NO can only have the value 3. For the Picasso 2000 and Rubens, NO can have any value between 0 and 3, which corresponds to output 1 to 4. In any case no more than one PWM output can be handled at any one time.

PRESCALER (period) and BITR (resolution) are two parameters whose values can be obtained from the table shown in the following section. If all three parameters are set to 0, the PWM function is disabled.

After using the G68 H7 command, it is possible to set the desired ratio between the axis speed and the duty cycle, by means of the @52 command.

When defining the speed–duty cycle ratio, the field for output voltage is to be filled with the duty cycle percentage; the range is 0 to 10, where 0 means 0% and 10 means 100%.

The duty cycle resolution is defined by:  $100/2^{(BITR)}$ .

## OUTPUT FREQUENCY AND RESOLUTION

As stated in the introduction, a relation exists between the frequency used in the PWM output and the resolution that can be obtained.

The following table shows the available output frequency values (in Hz) and the corresponding resolution.

The first column shows the divisor of the internal clock frequency (2, 4, 8, ...), while the second row shows the resolution bits in the setting of the duty cycle (16, 15, 14, ...).

For instance, let's assume that a PWM signal is required, with a frequency ( $F_{pwm}$ ) greater than 10 kHz. The resolution must be as high as possible (maximum BITR), as this is always required to guarantee the best laser control.

Searching in the table, we have to find the first frequency greater than 10 kHz. We can see that a frequency of 10239 Hz is available for some pairs of (PRESCALER, BITR) values: (0,10), (1,9), (2,8) and so on. We have to choose the highest resolution, and so the pair PRESCALER=0 & BITR=10 is the correct one. In this way, the PWM signal will have a frequency of 10239 Hz, with a 10 bit resolution. This resolution ensures that  $2^{10}=1024$  possible values of duty cycle are available.

The command to be set is therefore **G68 H7,0,0,10**.

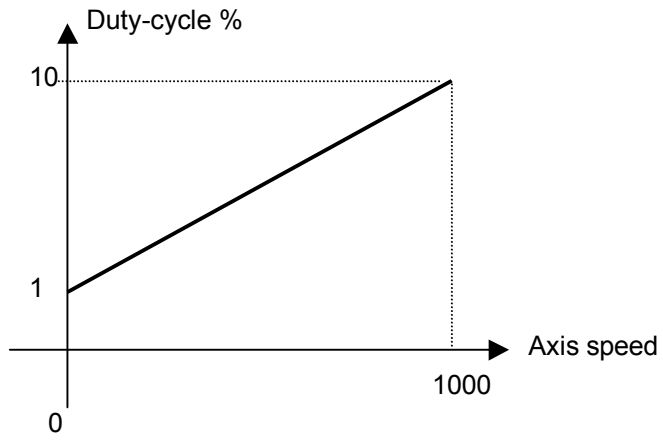
PRESCALER	BITR															
	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
0	160	320	640	1280	2560	5120	10239	20479	40957	81914	164K	328K	655K	1311K	2621K	5243K
1	80	160	320	640	1280	2560	5120	10239	20479	40957	81914	164K	328K	655K	1311K	2621K
2	40	80	160	320	640	1280	2560	5120	10239	20479	40957	81914	164K	328K	655K	1311K
3	20	40	80	160	320	640	1280	2560	5120	10239	20479	40957	81914	164K	328K	655K
4	10	20	40	80	160	320	640	1280	2560	5120	10239	20479	40957	81914	164K	328K
5	5	10	20	40	80	160	320	640	1280	2560	5120	10239	20479	40957	81914	164K
6	2.5	5	10	20	40	80	160	320	640	1280	2560	5120	10239	20479	40957	81914
7	0.6	1.3	2.5	5	10	20	40	80	160	320	640	1280	2560	5120	10239	20479

The minimum Ton time depends on the system clock and is always equal to  $T_{pwm}/2^{BITR}$ , i.e. about 95 ns.

## EXAMPLES FOR USING COMMANDS G68 H7 AND @52

G68 H7,3,0,11 ; a frequency of 5120 Hz is defined, with a resolution of 11 bits on outlet 3

@52 I0,1 1000,10 ; when the speed is 0, a 10% duty cycle is desired, while when the speed is 1000 a 100% duty cycle is desired



G68 H7,0,0,0 ;the PWM output is disabled