Application Criteria Relevant to RFI (EMC) Disturbance Suppressing Electric Filters for Low Voltage Machines and Installations

The European Directive 2004/108/EC, obliges the manufacturers of industrial machine tools and electric and electronic equipment to comply with the standard Electromagnetic Compatibility (EMC) emission and immunity levels.

This report refers the definitions and the classification relevant to electromagnetic disturbances and the basic application criteria of RFI (EMC) Low Voltage (< 1000 V) disturbance suppressing filters.

1. Definitions

1.1 Electromagnetic interference

Electromagnetic phenomenon that can degrade the functional characteristics of an electronic energised or not energised equipment or system.

1.2 Electromagnetic Compatibility (EMC)

Electromagnetic Compatibility (EMC) commonly refers to the ability of equipment or system to satisfactory operate in its electromagnetic environment without introducing intolerable electromagnetic interference (EMI) to anything in that environment.
The Electromagnetic Compatibility (EMC) includes two important aspects (emission and immunity) described below.

1.2.1 Electromagnetic Emission

Phenomenon by which the electromagnetic energy is emitted from a source: a device, a machine or a system shall not emit undesirable electromagnetic interference of a higher level that those allowed by the European EMC Framework 2004/108/EC **(see figure 1)**.

1.2.2 Immunity (to interferences)

Capability of equipment, machine or system to correctly operate, when affected by electromagnetic interference, without degrading their functional characteristics.

2. General classification of interference

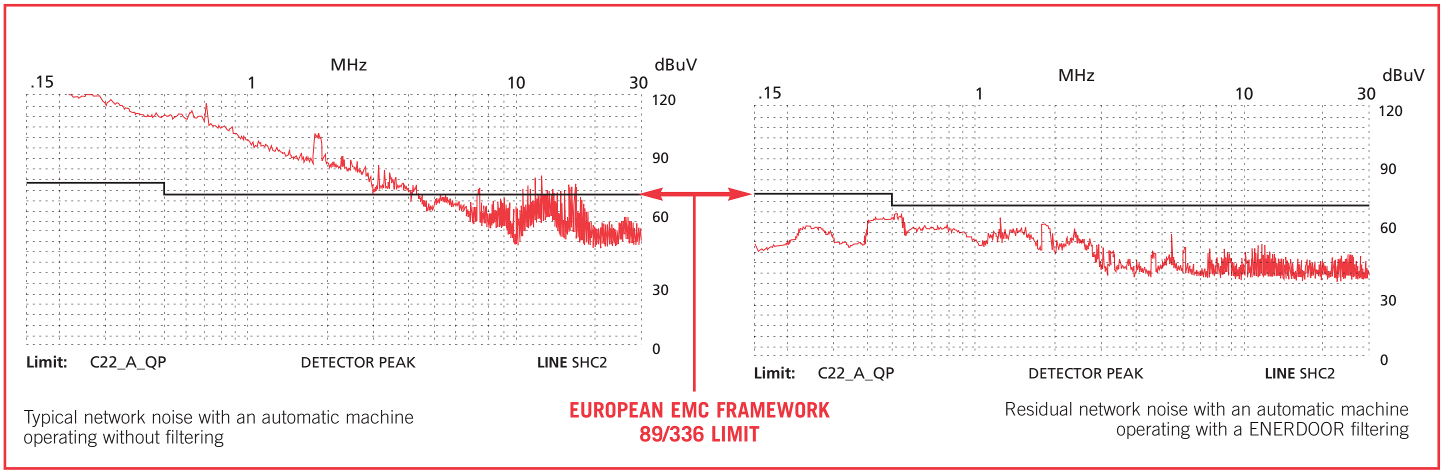

Figure 1:
Example of typical disturbances generated by an automatic machine operating without and with filtering necessary to comply with the European EMC Framework 89/336 limits.

2.1 Conducted and radiated interference

Interference can be classified as follows:

a) conducted interference, is the undesirable voltage or current signals that enter or exit from a specific device through its own signaling or energising electric conductors.

b) radiated interference, is the undesirable signals present as an electromagnetic field in the surrounding space. Every electric or electronic circuit acts like an aerial; therefore when it is dipped in an electromagnetic field this induces an interference voltage in it while when it is crossed by a variable current it generates an electromagnetic field.

Making reference to the above classification, each variable current flowing in an electric conductor creates an electromagnetic field in the surrounding environment and similarly each electromagnetic field induces an electric signal in a close conductor. Therefore, the distinction between radiated and conducted interference is mainly due to practical motivations.
It is pointed out that the above distinctions allow to classify better the undesirable signals, which at lower frequencies are mainly conducted distrurbances while at higher frequencies can be detected only using aerials and therefore are mainly radiated disturbances.

2.2 Common Mode and Differential Mode Interference

2.2.1 Common Mode Interference

A common mode interference is an undesirable signal as measured between all conductors of an electric circuit connected together and a common reference, usually the earth **(see figure 2)**.

2.2.2 Differential Mode Interference

The differential mode interference is an undesirable signal as measured between two independent conductors of the same electrical circuit **(see figure 3)**.

2.3 Interference recognisable in nature

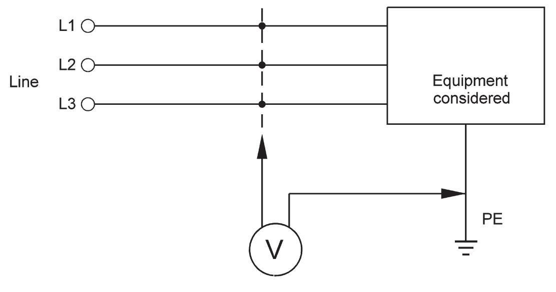

Fig. 2: Common Mode Interference

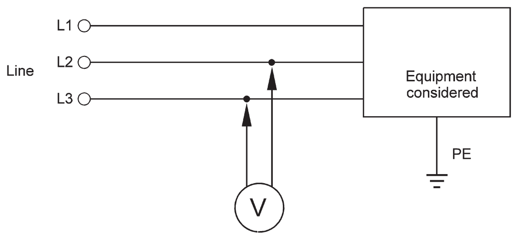

Fig. 3: Differential Mode Interference

2.3.1 Classification of electromagnetic phenomena

The electromagnetic phenomena can be classified considering the following specific characteristics:

a) frequency range: the most significant interference is characterised by a frequency range from a few kHz to hundreds of MHz, but the upper limit of the frequency range of interference is about 400 GHz;

b) interference physical characteristics: type of sources, effects, measuring methods and test; the interference is usually classified as:
- low frequency disturbances (f ≤ 150 kHz);
- high frequency disturbances (f >150 kHz).

c) Origin of interference: (conducted or radiated origins, electrostatic discharge, etc)

2.3.2 Interference classification

a) Conducted interference due to low frequency phenomena:
- mains 50/60 Hz harmonics and sub-harmonics;
- signalling systems;
- voltage variations interruptions and dips;
- voltage unbalances;
- mains 50/60 Hz frequency variations;
- low frequency induced voltages;
- DC components in AC.

b) Conducted interference due to high frequency phenomena:
- inducted voltages or currents (continuous or modulated waves);
- unidirectional transients (single or repetitive: burst);
- oscillatory transients (single or repetitive).

c) Radiated interference due to low frequency phenomena:
- magnetic fields (transients or continuous);
- electric fields.

d) Radiated interference due to high frequency phenomena:
- magnetic fields;
- electric fields;
- electromagnetic fields (transients, continuous or modulated wave).

e) Interference due to electrostatic discharges:
- electrostatic discharge.

3. Reduction of the Interference Levels:

RFI (EMC) filters

The devices able to reduce the electromagnetic interference (conducted and/or radiated) are called RFI (EMC) filters. A filter can be represented as shown in **figure 4**.

The filters are bi-directional devices; therefore they reduce undesirable signals measured on their output terminals in comparison with those that appear on their input terminals or vice versa. Due to their above bi-directional characteristics the filters are devices, able to reduce the level of emitted disturbances and also to increase the immunity level of filtered equipment or systems.

3.1 Active and passive filters

a) Active filters
Active filters are devices in which mainly active components are used.

c) Passive filters
Passive filters are devices in which only passive components, as resistances, inductances and capacitors, are used.

3.2 Single-phase and three-phase filters

a) Single-phase filters
These filters are suitable for application on single-phase equipment or electric installations (see **figure 5**).

b) Three phase filters
These filters are suitable for application on three phase equipment or electric installations (see **figure 6**).

3.3 Single and double function filters

a) Single function filters
The single function filters, because of their typical constitution, are RFI devices able to efficiently attenuate only common mode interference.

The schematic diagram of ENERDOOR single function filter type FIN 538 is shown in **figure 7**.
This type of filter typically allows a maximum attenuation level of common mode interference of about 60÷70 dB.

b) Double function filters
Double function filters are more complex devices than the above single function ones; they allow to efficiently attenuate both common mode and differential mode interference.

The schematic diagram of ENERDOOR double function filter type FIN 1500 is shown in **figure 8**.
This type of filter allows a maximum attenuation level of interference sometimes higher than 80 dB.

The ENERDOOR three phase filters type FIN538S..., FIN538S1..., FIN1200..., FIN1500..., FIN1600..., FIN1700..., FIN 1900..., FIN 1740..., FIN1940... and single phase filters type FIN 33, 35, 40, 50 are double function filters.

3.4 Series and parallel filters

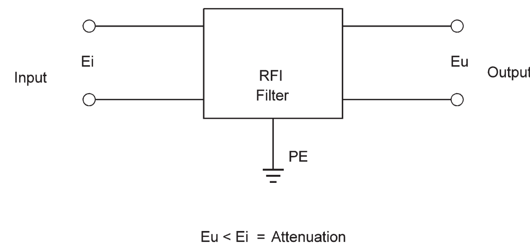

Fig. 4: Typical representation of a RFI Filter

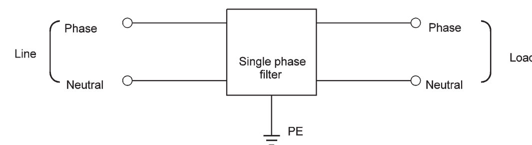

Fig. 5: Schematic diagram of a single phase filter

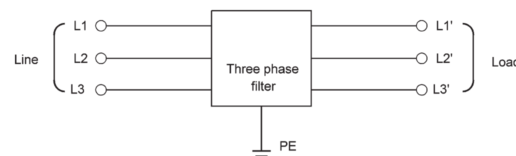

Fig. 6: Schematic diagram of a three phase filter

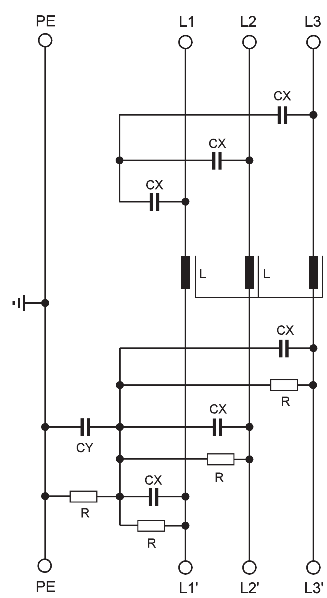

Fig. 7: Schematic diagram of ENERDOOR single function filter type FIN 538

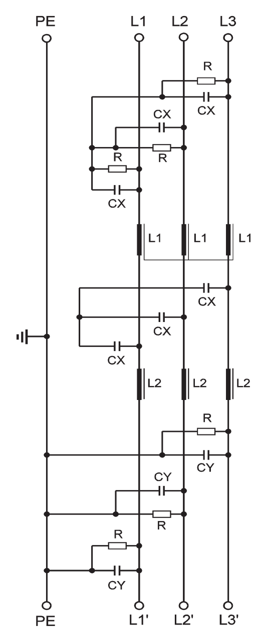

Fig. 8: Schematic diagram of ENERDOOR double function filter type FIN 1500

a) Series filters

The series filters represent the most widespread RFI filters; they are typically connected in series between the energized electric point and the load (machine tool electric installation, etc).

The total load current flows through the inductive components of a series filter and therefore it must be suitable to support it (see **figure 9**); the capacitive and resistive components of this filter are instead connected in parallel and therefore they absorb only a very low current from the mains.

The ENERDOOR three-phase filters type FIN 538, FIN 538S, FIN538S1, FIN1200, FIN1500, FIN1600, FIN1700,FIN 1900, FIN 3755, FIN 1240, FIN 1740, FIN 1740ESM, FIN1940 and single phase filters type FIN 33, 35, 40, 50 are series RFI filters.

b) Parallel filters

The parallel filters shall be connected in parallel to the mains; therefore their inductive, resistive and capacitive components absorb only a small current, independently of the level of load current. The typical application scheme of the single-function ENERDOOR FIN 130SP, 230SP, 730, 735, 740 parallel filters are shown in **figure 10**.

The FIN 130SP, 230SP, 730, 735, 740 parallel filters have been developed by ENERDOOR to increase the attenuation level for lower frequency interference, and particularly those included in the range between a few kHz and a few MHz, and also to protect the electronic control devices of industrial automatic machines from short duration high voltage surges.

This last characteristic is in particular included in the filter FIN 230SP (surge protection).

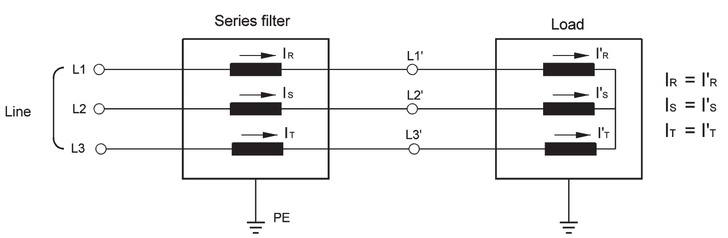

Fig. 9: Example of connection of a series filter: the total load current flows through the inductive components of the filter

Note: An example of a simple series filter is represented by a common mode choke (for example a ENERDOOR choke series FIN 900) to be connected between the inverter and the load. The above choke application allows an important reduction of radiated interference and a lower attenuation of the conducted interference present on the mains.

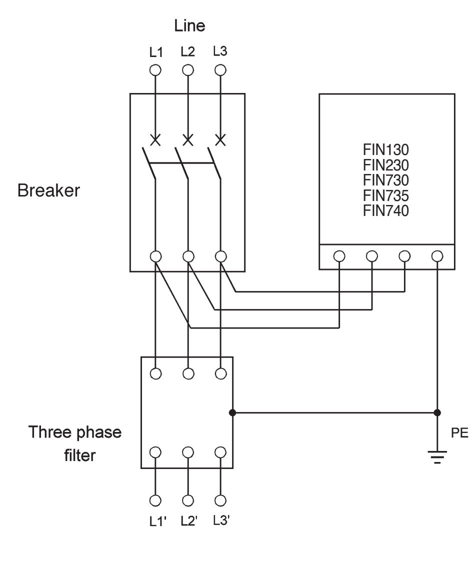

Fig. 10: Application diagram of single-function ENERDOOR FIN 730 and FIN 230SP parallel filters

4. Normative references

4.1 European EMC Framework (Directive) 89/336

Since 1st January 1996, in accordance to European Framework 89/336 relevant to Electromagnetic Compatibility (EMC), each device or machine (or installation) containing electric and electronic components that can emit interference or be disturbed by them shall:

a) not generate electromagnetic disturbances of higher level than that established by the above mentioned Directive, in order to allow the correct operation of all equipment installed in the surrounding environment;

b) to comply with the standard level of immunity, in order to avoid that the electromagnetic disturbances influence their behaviour in service.

4.2 Normative references for the emission and immunity tests

In order to be able to certificate that a device, machine or installation complies with the European Directive EMC 89/336 it is necessary to carry out a complete series of Electromagnetic Compatibility test, as below specified:

a) Emission test

STANDARD REFERENCE	TYPE OF EMC TEST
EN 55014	Conducted emissions
EN 55014	Radiated power
EN 55014	Intermitted interference (click)
EN 55011	Conducted emissions
EN 55011	Radiated emissions
EN 55022	Conducted emissions
EN 55022	Radiated emissions

b) Immunity test

STANDARD REFERENCE	TYPE OF EMC TEST
EN 61000-4-2	Electrostaticdischarges immunity
EN 61000-4-3	Rf radiated immunity
EN 61000-4-4	Immunity to fast transients (burst)
EN 61000-4-5	Immunity to high energy transients (surge)
EN 61000-4-6	Conducted immunity
EN 61000-4-8	Power frequency magnetic field immunity
EN 61000-4-11	Immunity to voltage dips and variations

5. Classification of industrial environments in accordance with the EMC level

5.1 General

As previously indicated there are many causes of the EMC interference origin.
Particularly electromagnetic interference can originate inside or outside the device, machine or installation considered.

The interference of internal origin mainly cause electromagnetic emission problems, while those of external origin involve immunity problems.
A RFI (EMC) filter must be capable to adequately reduce both internal and external origin disturbances in order to solve the whole problem of electromagnetic compatibility of the device, machine or installation concerned.

5.2 EMC environment classification

In order to give some useful information concerning the choice of the most adequate RFI (EMC) filter relevant to a specific application, the environments are classified, in accordance with the EMC interference levels , as follows:

- normal (low EMC interference levels);
- severe (medium EMC interference levels);
- very severe (high EMC interference levels).

The emission and the immunity tests (see clause 4.2) allow to verify that a device, machine or installation are adequate for a specific EMC environment.

6. Choice of ENERDOOR RFI (EMC) filter in accordance with the EMC environments

6.1 Residential, commercial and light industry environment

ENERDOOR filters to be used are:

- for single phase circuits: FIN 40 or FIN 50 filter;
- for three phase circuits: FIN538, FIN538S, FIN538S1, FIN1200, FIN1700, FIN1700E, FIN1700G, FIN1700EG, FIN 3755 double function filters

6.2 Industrial environment (severe environment)

ENERDOOR filters to be used:

- for single phase circuits: FIN 35, 40, 50 filter;
- for three phase circuits: FIN538, FIN538S, FIN538S1, FIN1200 (o HV*), FIN1500 (o HV*), FIN1600, FIN1700, FIN1700E, FIN1700EG, FIN1900, FIN1900E, FIN1900G, FIN1900EG, FIN1900S, FIN3755, FIN1240, FIN1740, FIN1740ESM, FIN1940 double function filters

(*) The FIN 1200 and 1500 HV filters presents the same attenuation characteristics as the filter FIN 1200 and FIN 1500 but have a nominal voltage of 600 V - 50 Hz instead of 440 V - 50 Hz.
For rated current higher than 500A the filter FIN 1500 shall be always proposed.

6.3 Industrial environment (very severe environment)

ENERDOOR filters to be used are:

- for single phase circuits: FIN 35,40 50 filter;
- for three phase circuits: FIN538, FIN538S, FIN538S1, FIN1200 (o HV*), FIN1500 (o HV*), FIN1600, FIN1700, FIN1700E, FIN1700EG, FIN1900, FIN1900E, FIN1900G, FIN1900EG, FIN1900S, FIN3755, FIN1240, FIN1740, FIN1740ESM, FIN1940 double function filters; FIN130SP, FIN230SP, FIN730, FIN735, FIN740

6.4 Filter to propose for a specific application

The information referring to the previous clauses represents only some general suggestions relevant to the application of ENERDOOR filters.
A more precise match between a device, machine or installation and a RFI filter can be decided only after having carried out the complete series of emission and immunity EMC tests.
It is also pointed out that, on a specific request, the EMC laboratory of the FINLAB Company, that is connected with ENERDOOR, can perform all the necessary EMC tests.

7. Application example

This clause gives an application example for filters and chokes of ENERDOOR. Making reference to the schematic diagram reported in figure 11, the choice of the better filter(s) for the specific application can be verified using the criteria described below.

7.1 Filter parameters

a) The reference power of the filter satisfies to the known formula:

$$P = \sqrt{3}\, V \bullet I \cos\varphi$$

P is the total power of devices and motors of the considered system;

V is the phase to phase nominal voltage of the installation (for example 400V-50 Hz);

cos φ is the average power factor; for it can be typically assumed the value 0,7.

b) The nominal current (I) of the filter derives from the previous formula, as follows:

$$I = \frac{P}{\sqrt{3} \bullet V \bullet \cos\varphi}$$

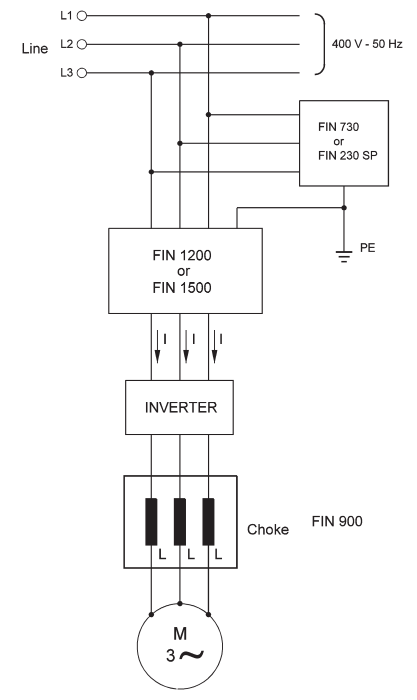

Fig. 11: Typical electric diagram relevant to the application of ENERDOOR filters and choke

Note: The low voltage breaker is not represented.

7.2 Calculation example (see figure 11)

For an installation which total power P corresponds to 85 kW and the phase to phase voltage corresponds to 400 Volts, what is the ENERDOOR filter to be used?

a) It can be assumed for the power factor cos j the value 0,7.
Now, knowing: the power **P**, the voltage **V** and the **cos φ**, the value of current can be calculated as follows:

$$I = \frac{P}{\sqrt{3} \bullet V \bullet \cos\varphi} = \frac{85.000}{\sqrt{3} \bullet 400 \bullet 0,7} \simeq 175 \text{ A}$$

Therefore, the more adequate ENERDOOR filter for this specific application is that with the nominal current of 200 A.
In accordance with the type of EMC environment (typically severe or very severe), can be therefore used the double function filter (and eventually with one single function parallel filter).

b) Concerning the choke, to be installed between the inverter and the motor, it shall have a nominal current higher than that calculated for the filter; this is mainly due to the following effects:

- the working frequency PWM of the inverter is usually included between 5 and 20 kHz, this causes an augmentation of the choke losses and the consequent increasing of its temperature;

- the output current of the inverter, during the motor acceleration and deceleration, can also reach double of its nominal current, for a duration of about one minute.

Practical experience suggests to use a choke over-dimensioned by about 50% in comparison to the corresponding RFI filter nominal current. Therefore, for this application example a ENERDOOR choke with nominal current equal to 280 A can be used.