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"Considerations on a Method for Setting Out the Conservation Project"

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CONSIDERATIONS ON A METHOD FOR SETTING OUT THE CONSERVATION PROJECT
An example relating to the use of the computer in the development of the model of the thermodynamic system Marcus Aurelius - Capitolium Square

1. The phases of the conservation project

An object of historical and/or cultural interest is a structure constituted by an assembly of materials. It therefore undergoes decay due to a complex series of physical, chemical and biological processes that interact and condition each other. Consequently, a change in the figures of the materials it is constituted by, takes place. The primary causes of these events have to be searched for in the internal and external stresses that, acting on the structure, prevent it from reaching a "quiet state"; the direct consequence is the decay in its physical-mechanical consistency and in its historical and cultural readability. Any structure is always subject to stresses, consequently the decay is an unavoidable process. Is takes place at a speed which is in relation with the number, intensity, gradient and frequency of the stresses. These can be, theoretically, divided into two classes:
- "physiological" stresses;
- shocks.

Physiological stresses are due to the typical behaviour of the structure and of its environment. In this class, one can consider such phenomena as daily and seasonal thermal variations, mechanical settling, electrochemical corrosion, atmospheric pollution, etc.

Shocks, instead, are due to random events which cause sensible variations in the structure-environment system and may have "violent" effects on the structure itself. In this class one may consider events such as earthquakes, floods, the lightning which fell upon the Flaminio Obelisk in Rome, but also events such as the sudden unearthing of archaeological structures.

A conservator should aim to increase the "survival period" of the structure, lowering, in the space-time dimensions, the probability of shocks and the existence of physiological stresses. In this way it is possible to lower the dynamic of the decay process.

As emphasised in the previous examples, the environment is a basic element for the dynamics of the structure. In fact, it interacts with the object; directly, by causing, for instance, dimensional variations and consequent mechanical stress in the constitutive materials; indirectly, by causing, for instance, condensation-evaporation cycles. Therefore lowering the variations (in space and time) of the thermodynamic figures means to optimise, in an environmental point of view, the conditions for a probable good survival of the structure. Moreover, the closer the average values of such figures will be to the object most suitable ones, the better will be the situation.

In the case of a structure which has to be removed from its original site, it will be necessary to plan an environment that should have the most suitable characteristics in temperature and relative humidity, to study the method of realisation of such an environment, the ways and times in which the transfer operations have to take place in order to avoid as much as possible shocks and problems.

The problem is even more complicated in the case of a structure that cannot be moved or for which the removal should be an extreme operation. In such a case the thermodynamic figures are not defined before hand, but they have to be determined by a study of the behaviour of the structure. Moreover the operations in project to optimise such figures will be conditioned by considerations relating to the respect for the environment itself under the conservative, historical, cultural, social, town-planning and ecological points of view.

Generally, before defining an operation as useful and efficient, it is necessary to forecast its effects on the structure-environment system. An operation will be correct when it solves (in short and medium periods) the problem it has been planned for, and when it does not introduce other potential causes of decay. It is therefore obvious that the more one knows about the structure, the environment and their mutual interactions, the greater is the probability that such a forecast will be valid. In other words, before an operation is executed, it is necessary to accomplish a series of studies and surveys from which the theoretical model of the behaviour of the system can be drawn.

Considering the large amount of phenomena that take place in the process of decay and their complex mutual interactions, the design of models has to be developed through a process based on theoretical considerations and direct observation. Practically, the first phase consists in defining the figures that are fundamental for the design of such a model. These figures will then be placed under control. The collected results will be evaluated so that a first theoretical hypothesis could be defined. Such a model can then be compared to successive observations on field to check whether and in what measure events, forecast by it, take place. The more the "forecast" events take place, the higher is the probability that the model is correct. If the theoretical model is sufficiently reliable, it can be used to continue investigating the system. Even the differences in behaviour between the theoretical and the experimental schemes are useful: in fact, the analysis of such differences can be very important to define the contribution of phenomena that have been ignored in the preceding model. If these phenomena result to be significant, they have to be put under control by a properly organised collection of information and data on field. Ultimately, the obtained information will be important in the design of a new theoretical model. This "dialectic process" will reach an end when the designed model proves to be sufficiently reliable and complete. On the basis of models of this kind it will be possible to design "maps of risk" for the structure, aimed to determine, in a space and time dimension, the probability that potentially negative events for the survival of the object, could take place.

Therefore, theoretically, the conservative project must be developed in three phases:

- examination phase: aimed to accomplish observations on the structure, its environment and behaviour, by the collection of information and data directly detectable and measurable;
- diagnosis phase: aimed to design the behaviour models and the maps of risk for the structure;
- therapy phase: aimed to plan and execute the correct conservative operations (including restoration).

Obviously, the division in three phases is more theoretical than practical. For instance, as it has been already shown, the examination and diagnosis phases influence and condition each other in a process of theoretical-experimental comparisons that can be called "diagnostic process".

2. Marcus Aurelius - an example of methodological praxis

An example of diagnostic process, relating to an environmental study, is given by the examinations and studies that have been accomplished on the equestrian monument of Marcus Aurelius. The ultimate aim was to create a behaviour model of the thermodynamic system composed by the structure (bronze statue) and its environment (Capitolium Square).

This paper will describe the steps by which it has been possible to define a first behaviour model of the system, relating to the definition, in space and time, of the distribution of the structure surface temperature.

Such an information is, in fact, fundamental from a microclimatic point of view (to design the maps of risk relating to evaporation and condensation cycles) and from a mechanical one (to define the thermal inertia of the different parts of the structure). The thermal distribution on the surface of a structure is a consequence both of the phenomena of heat exchange (radiation, convection, conduction) that take place inside and outside the structure and of the thermal figures (conductivity, specific heat, etc.) of the elements constituting the structure itself.

The first step for studying such a system has been to put under control the structure collecting values for its surface temperature, sampled in space (but practically continuos in time) by thermocouples, and sampled in time (but practically continuos in space) by thermovision. The use of both techniques has been decided to minimise the effects of definition uncertainty due to one single technique. In fact, thermovision gives a good information of thermal distribution in space, but just in the moments in which it is used,; similarly, thermocouples give data relating to the points of application. The correlation of data obtained by both techniques has given sufficient information to be able to design the first theoretical model of the structure-environment system. The main result of such an examination has been to define the basic elements of the thermodynamic system: statue, air, marble basement.

The following step has been to observe the environment. The Capitolium Square is placed at the centre of a natural saddle of the hill. In fact, toward NNE there is the Arce Capitolina (Capitolium Summit) covered by the buildings of Ara Coeli (height 32 m), then there is the right wing of the Altare della Patria (Tomb of the Unknown Soldier - height 43 m). Toward SSW there is Monte Caprino (Goats' Mountain) that has an average height of 6 m; considering the buildings existing on this side of the hill, the height reaches 13 m. Ultimately, the Square is bordered by Palazzo Senatorio (Senator's Palace - SSE, height 29 m), Palazzo dei Conservatori (Conservators' Palace - SSW, height 20 m) and Palazzo Nuovo (Newly-built Palace - NNE, height 20 m). All the heights are computed taking as zero the average height of the square.

The situation of the environment has an important consequence: it strongly conditions the times and ways in which the sun radiates upon the structure. The solar direct radiation is a basic element to define the heating dynamics of the structure and it was therefore extremely interesting to calculate how and when the sun rays reach the surface. With this aim in mind, a system has been realised which, through the theoretical computing of the height and position (in respect to the cardinal points) of the sun in each and every day and hour of the typical year, establishes the shadows created by the Capitolium buildings and, then, the insolation conditions of the structure. The computer system deals with the potential direct radiation of the sun; consequently phenomena of atmospheric diffusion are ignored. The model, if properly tested, can be a useful tool for the definition of the energetic dynamic balance of the structure and therefore in the determination of the areas and moments in which there is a possibility that potentially dangerous thermal variations can take place. To determine whether the system has a good degree of reliability it is necessary to compare the theoretical behaviour of the structure with data collected on field.

If you consider, for instance, the radiating dynamic computed for a typical day in the second half of August, it can be easily seen that, in this case, the theoretical model forecasts a dynamic of the following kind:
- in the earlier hours of the morning the structure is completely in the shade, due to the presence of Palazzo Nuovo;
- later, the monument passes to an insolation condition; the sun rays directly hit the posterior parts of the structure;
- in late afternoon the structure passes into the shade due to the presence of Palazzo dei Conservatori;
- at sunset, the sun rays hit, almost perpendicularly, the left foreword part of the monument.

Such a behaviour is extremely discontinuous; moreover, the danger is still greater due to the fact that bronze, having a rather low thermal inertia, follows rapidly the thermal stresses of the environment.

Consequently, it is possible to make the following theoretical considerations:
- the area that undergoes the greatest stress, under a thermal point of view, is the croup, exposed to the sun radiation in the warmer hours of the day;
- the right-hand side (in particular the rear area) is heated before the left-hand side, but the latter reaches a higher temperature as time passes. In fact in the morning the sun hits the right-hand side directly while later on it reaches the left-hand side (at midday the sun rays directly hit the rear left-hand side);
- in the morning the rear end of the statue is warmer than the front one; in the late afternoon the situation is inverted. In particular, the front area reaches its maximum temperature at sunset. In fact, in the morning and in the earlier afternoon, the sun rays directly hit the rear end of the statue while during the late hours of the afternoon they radiate toward the front of the right-hand

side, at sunset, they directly hit the front end of the statue with a direction that is almost perpendicular to it.

Examining the charts of the thermocouples data recorded during the same period, it is immediately possible to observe that the curves can be easily explained by the described theoretical considerations. In fact:

- the area that reaches the highest temperature value is the croup (thermocouple 4);
- the left-hand side (thermocouple 1) is always warmer than the right-hand side (thermocouple 7), except for the earlier hours of the morning;
- the rear end (thermocouple 2) is heated more rapidly than the front one (thermocouple 6), but its cooling off is also faster;
- the horse's chest (thermocouple 6) has a peak at sunset, when the temperature of all the other thermocouples is decreasing.

Besides these observations, it is necessary to make some other considerations from the thermocouples charts which cannot be directly compared with the described theoretical model:

- during the night the basement is warmer than the bronze statue;
- the daily variations of a single thermocouple cannot be superimposed over each other.

The first observation can also be confirmed by thermovision which completes the information by showing that the structure, during the night, has a thermal gradient which is inversely proportional to the level above the ground. This is due to the fact that the basement has a higher thermal inertia than the bronze statue. Due to the season and the hour of the recording, the temperature of the basement is higher than the one of the statue and consequently it radiates heat toward the monument causing a temperature increase in the areas that are geometrically more exposed to its influence.

A direct consequence of such an observation is that the marble basement cannot be ignored but it should be considered a basic component of the structure-environment system. Therefore for a complete and exhaustive thermodynamic model, it will be necessary to study the basement thermal variations and their influence on the monument.

The second observation confirms, on one side, the great influence of the sun direct radiation on the thermal dynamics of the structure. In fact, the tendency of the examined points is to follow the described behaviour. On the other side it demonstrates that the existence of other thermal processes (connected with evaporation, convection, etc.) can be particularly important in the phase of the design of maps of risk for the structure. The importance of such phenomena is particularly clear in the area P corresponding to a period of climatic instability (clear sky alternated with brief storms). It is also very interesting to consider the behaviour of thermocouple 6 (horse's chest) in the recordings of the last three days. In the last day it records a rather elevated gradient at sunset; such a gradient is, however, much lower in the preceding days. This behaviour may have been caused by more powerful convective effects which brought about, as a direct consequence, a faster thermal decrease when the structure entered into the shade (afternoon). This consideration seems to be confirmed by the fact that the sunset temperature peak is slightly lower in the last day.

These observations underline, once more, the importance of the influence that the various phenomena of heat exchange have on the surface thermal distribution.

The problem becomes more complicated due to the fact that the bronze structure is, in a thermal point of view, absolutely discontinuous. In fact, experiments accomplished in the laboratory have demonstrated that the differences in thermal inertia (due to differences in alloy composition, in form, in defects, in distribution of masses and thickness) are not negligible.

The next step of the study is aimed to design a map of the thermal discontinuity of the structure and its basement. In this way, it may be possible to compute the thermal figures of the bronze-marble system. The aim is to render quantitatively valid the realised theoretical model. At that moment, and only then, it will be possible to forecast the theoretical thermal distribution that the sun direct insolation produces on the structure and then, by investigation on site (on the basement) and in the laboratory, it will be possible to check and compute the influence that the other processes of thermal exchange have on such a distribution.

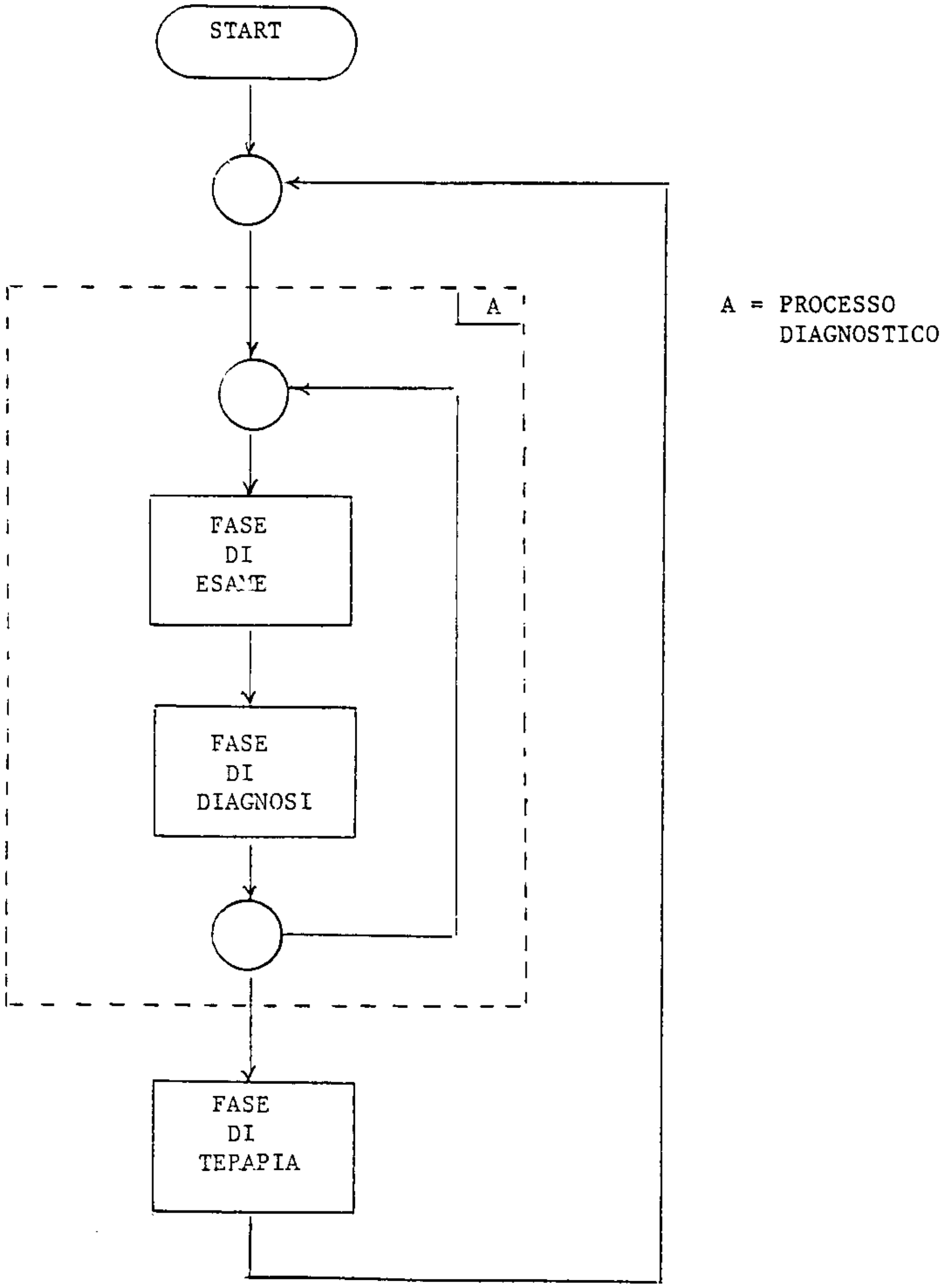
3. Conclusions

The described example immediately shows that the definition of a conservation project is an extremely difficult and exacting task. The examination of an existing structure, for which most of the physical figures are unknown (and often even the constituent materials and their distribution are unknown), means that the information and data collected on field should be filtered to associate them to the phenomena that have caused them. Nevertheless, the knowledge of these causes is fundamental for the definition of the mechanisms of the stresses acting on the structure itself. Consequently, it is necessary to support the observations accomplished through the measurements and controls of the environment-structure system. The information collected by the various techniques must then be correlated; but it should also be compared with theoretical models relating to the particular phenomena (thermodynamic, mechanical, etc.). It will then be possible to evaluate the importance of such phenomena in the general behaviour of the system.

The ultimate aim of this research is to design the global behaviour model of the structure. This is the only method which permits to forecast the possibility of application and the utility of each and every conservative and restorative operation on the structure and/or on the environment.

There is, yet, a lot of work to accomplish before such a goal can be reached. The research is now in a phase of "work in progress" and many problems (such as, for instance, the correlation of information and data relating to the various kinds of stimulation and stresses) must be looked into more deeply. The way Marcus Aurelius was examined constitutes an example, applied to a specific but particularly important case, of a methodological praxis which can presently give precious information, but that, if correctly developed, may represent, in the future (we hope not too far away) a fundamental element for the examination, the control and the defence of our cultural heritage.

PROCESSO PREVENTIVO DI CONSERVAZIONE



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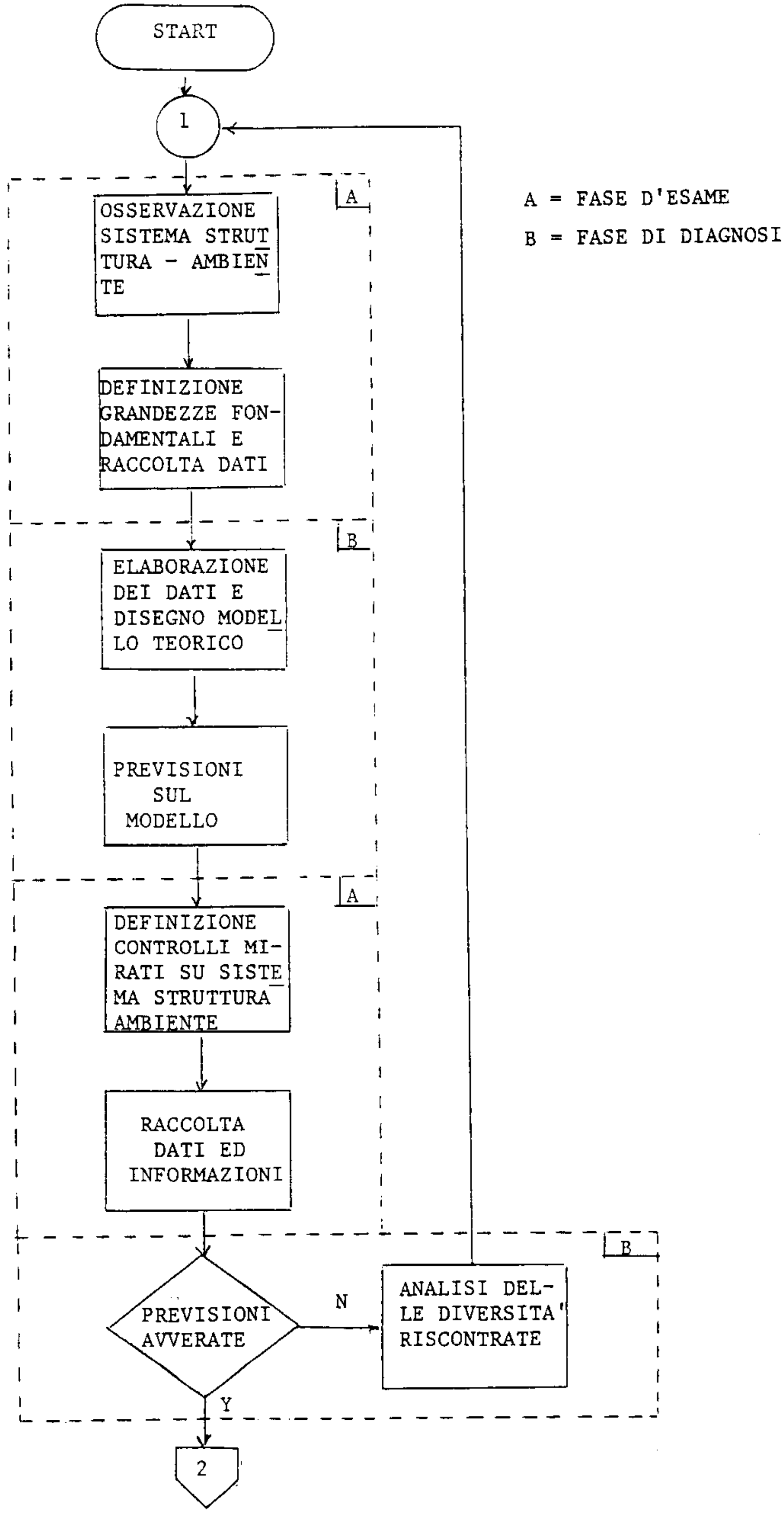

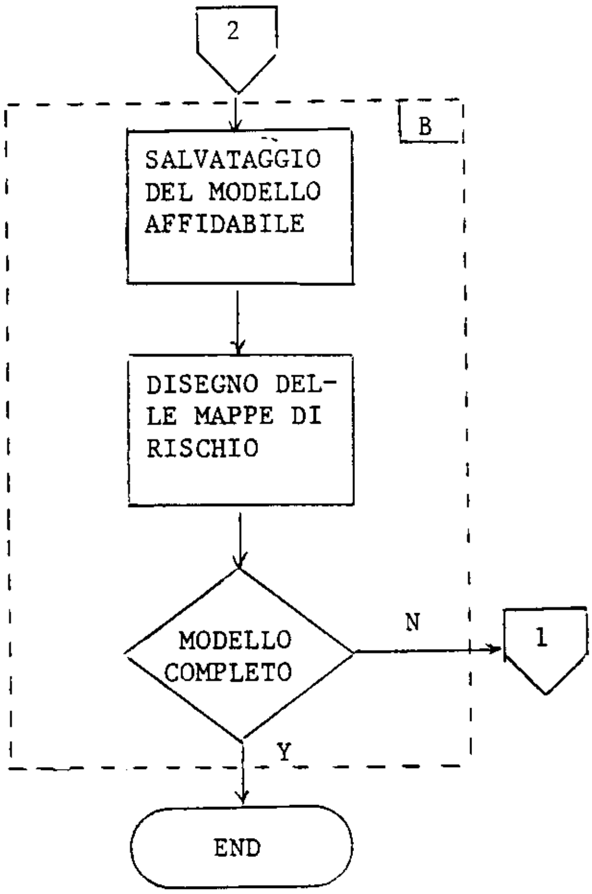
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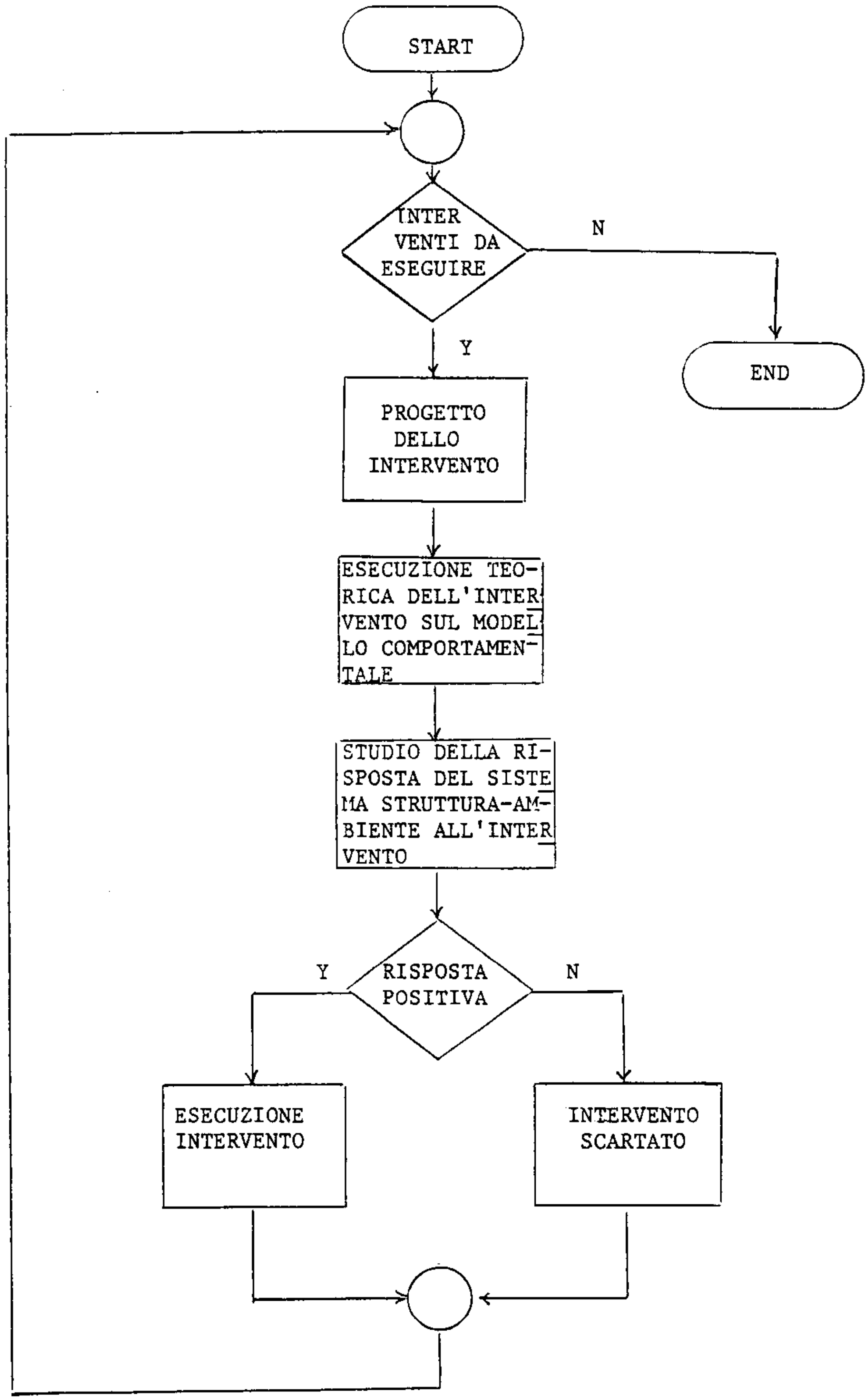

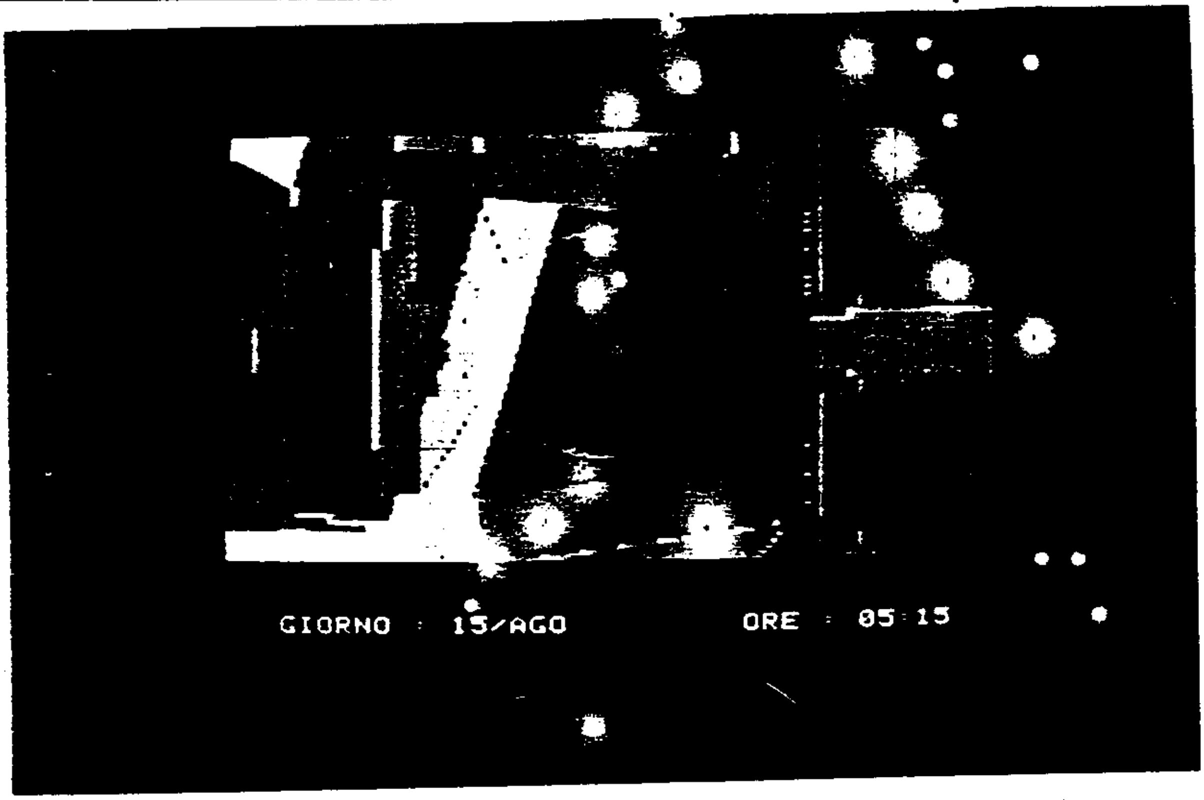

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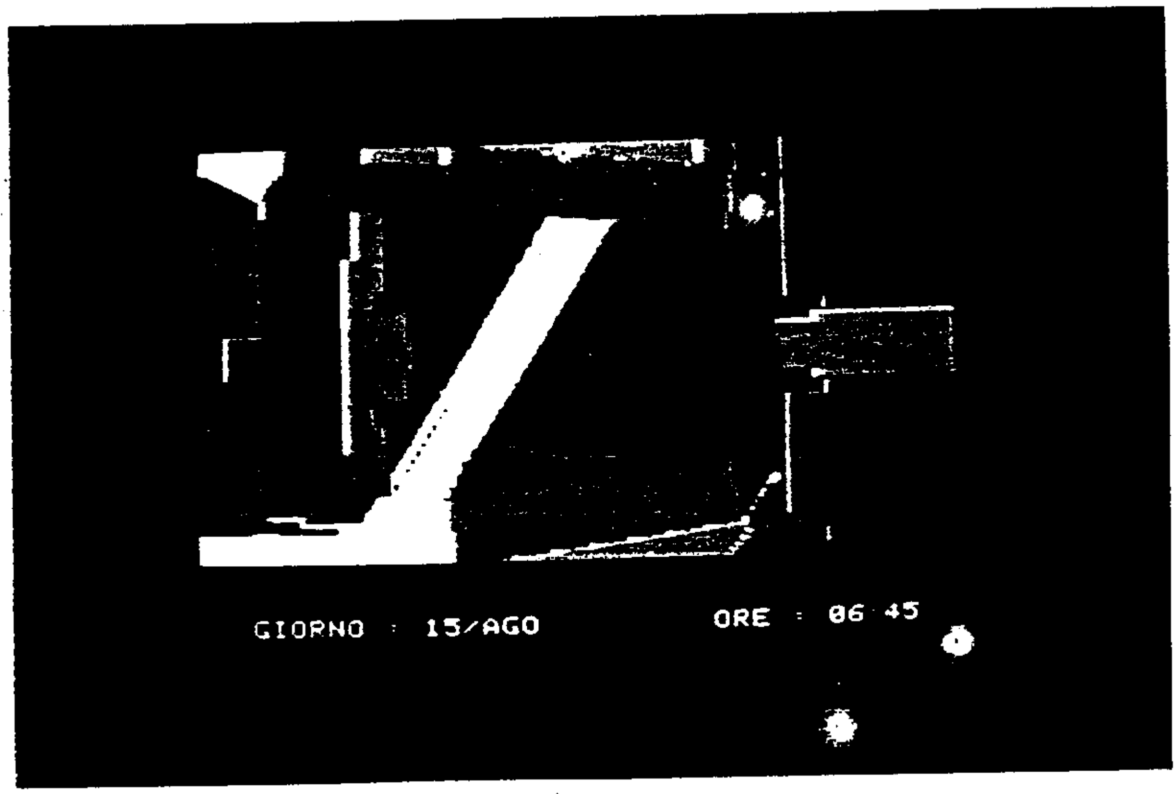

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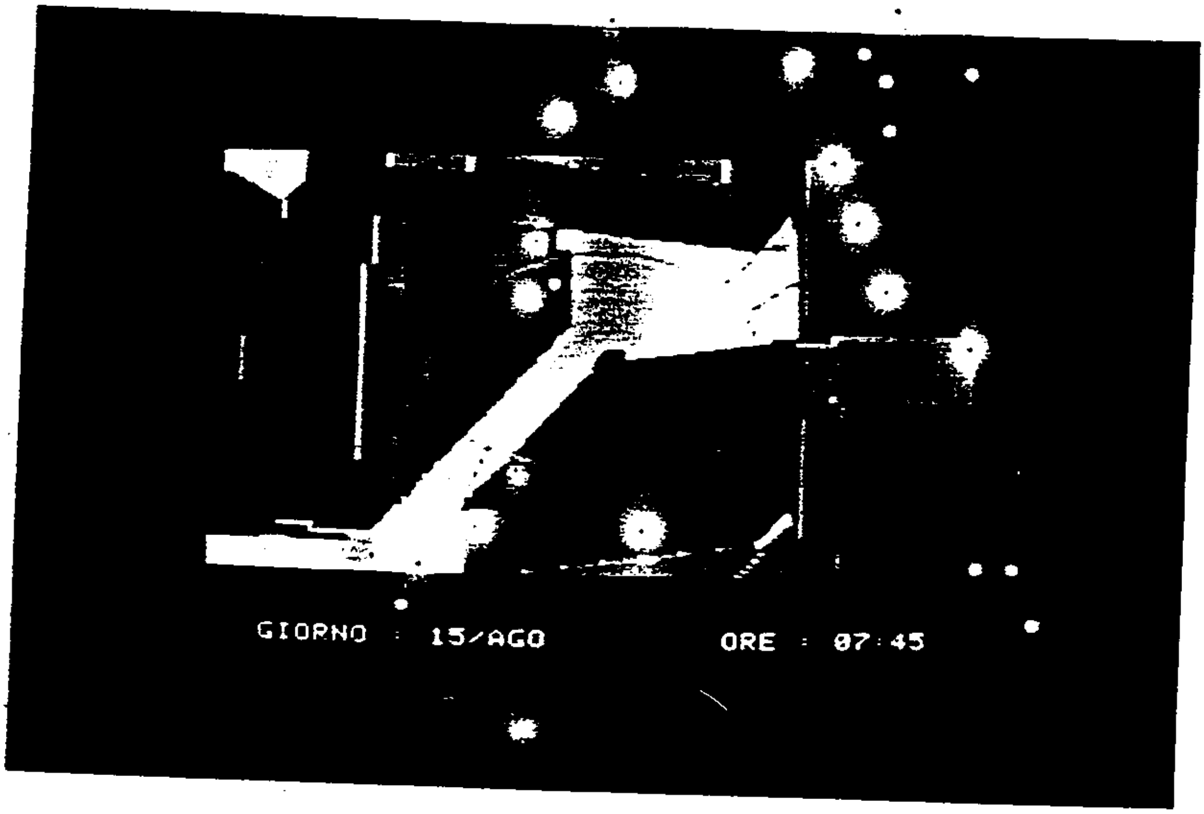
Fig. 2



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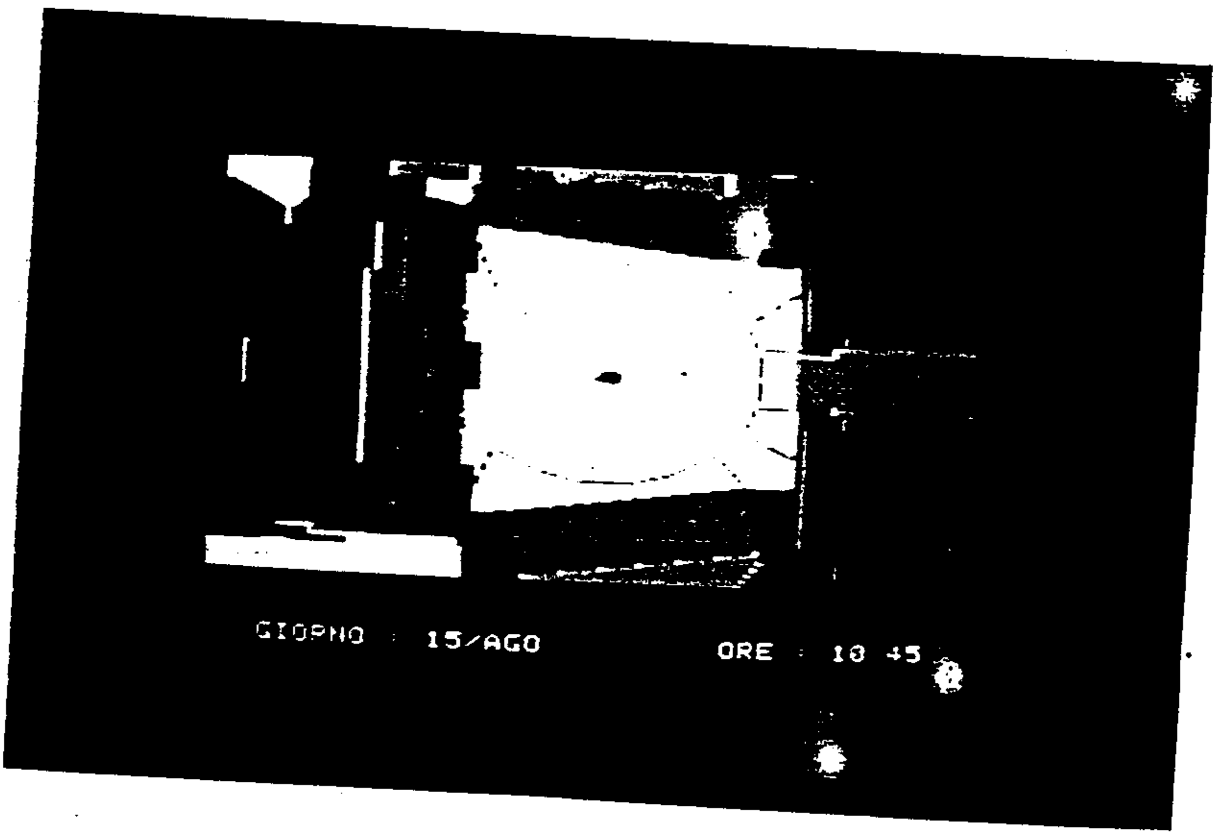

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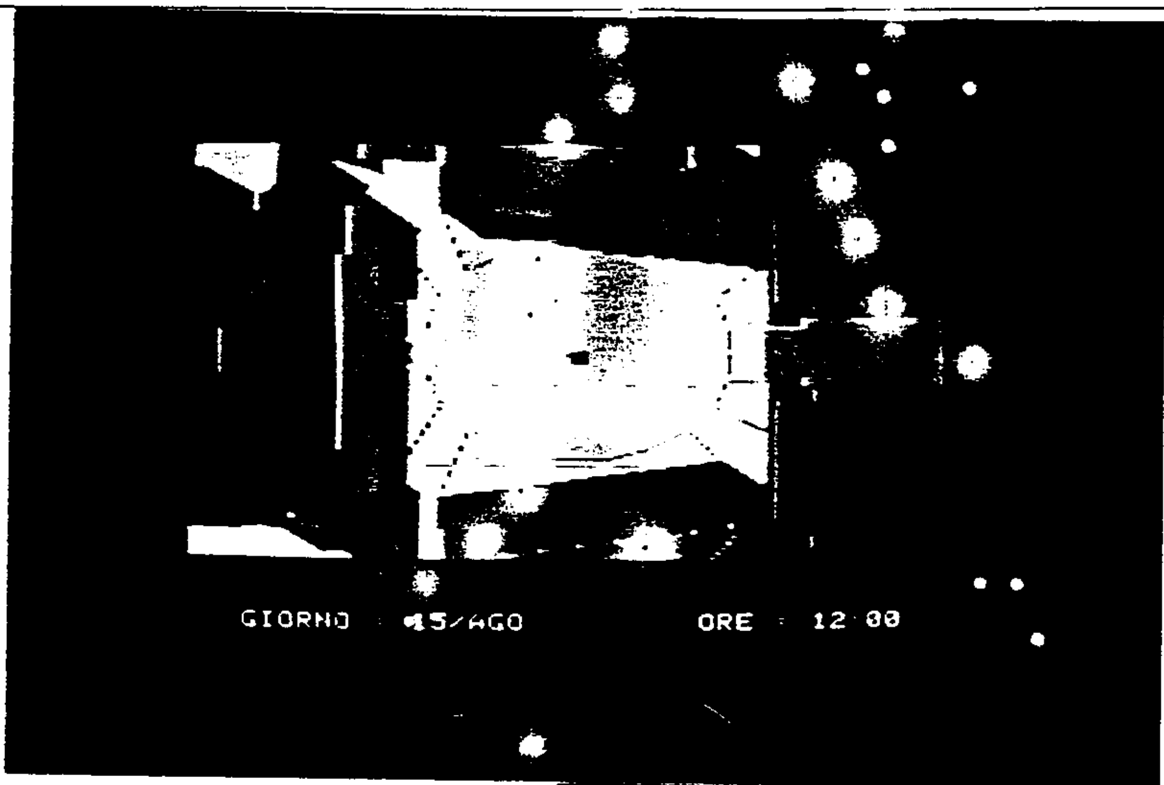
Fig. 2



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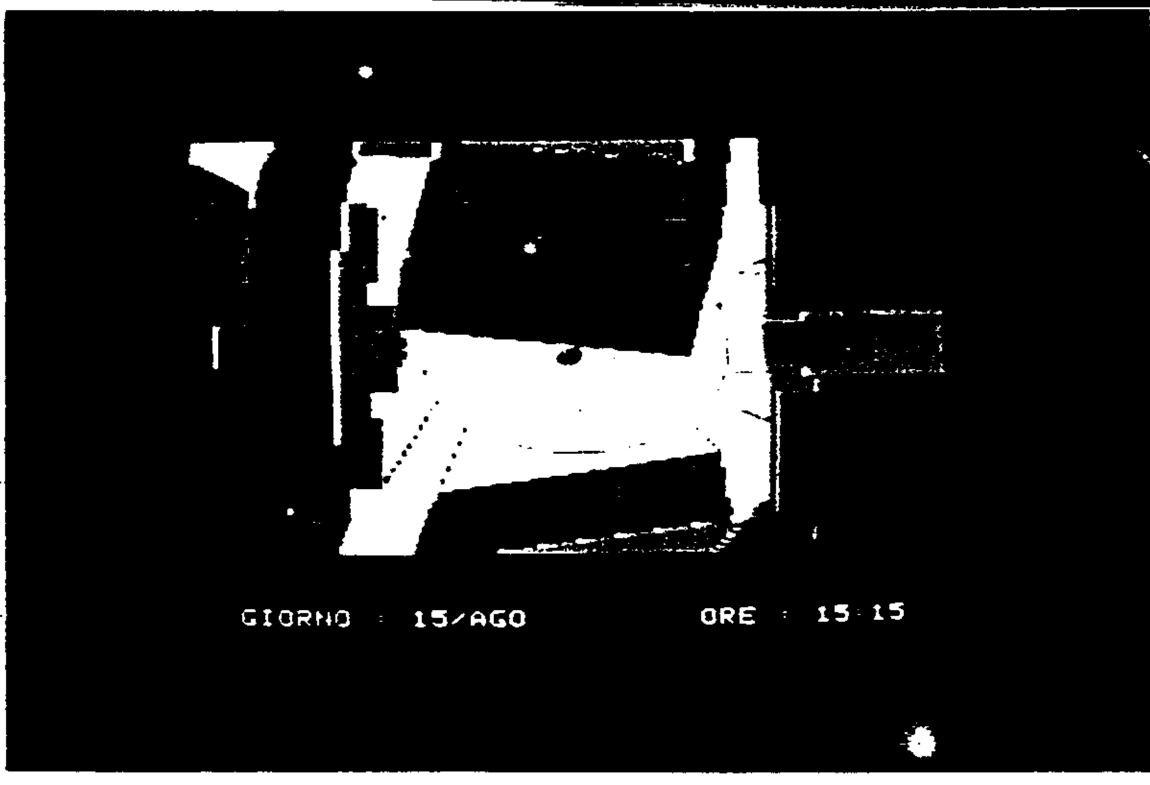

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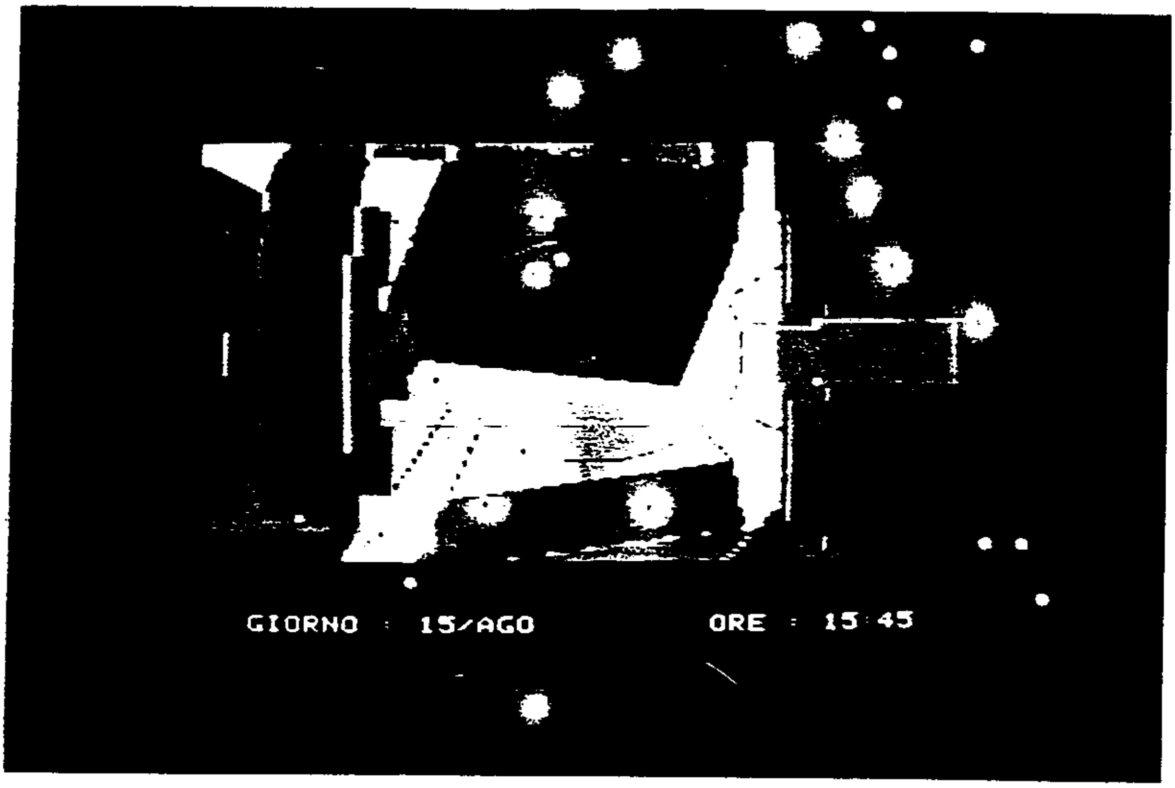
Fig. 2



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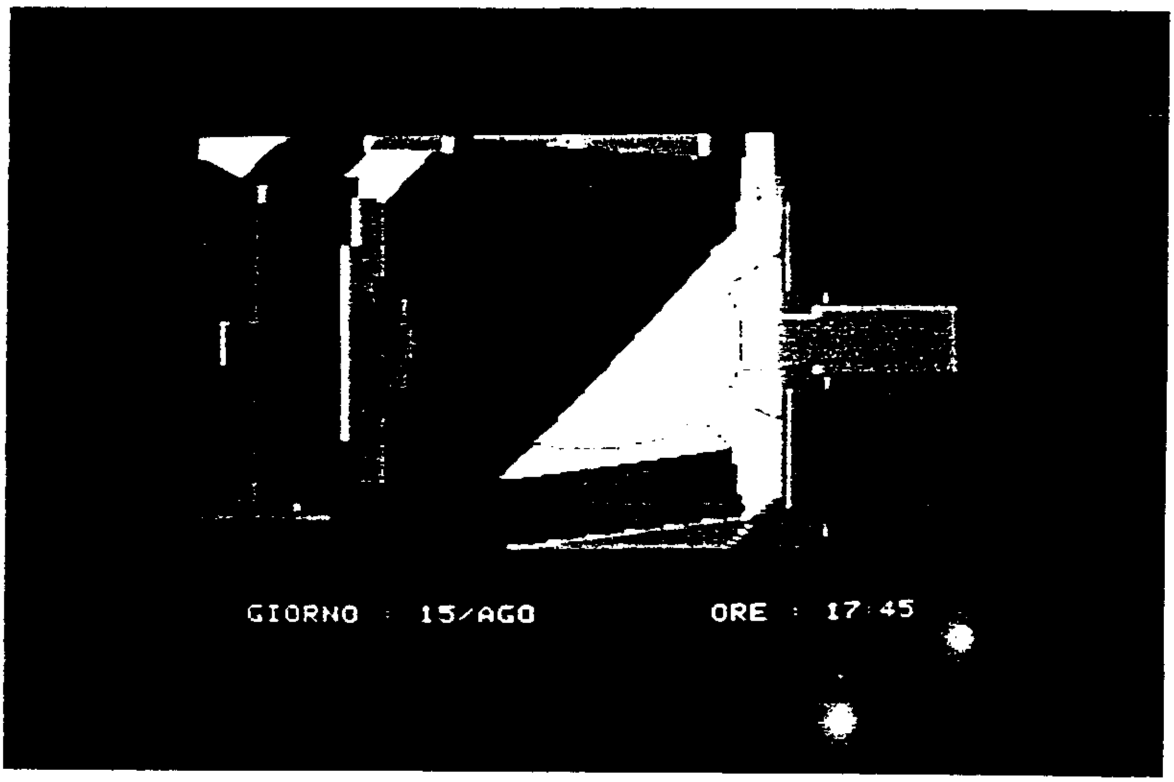

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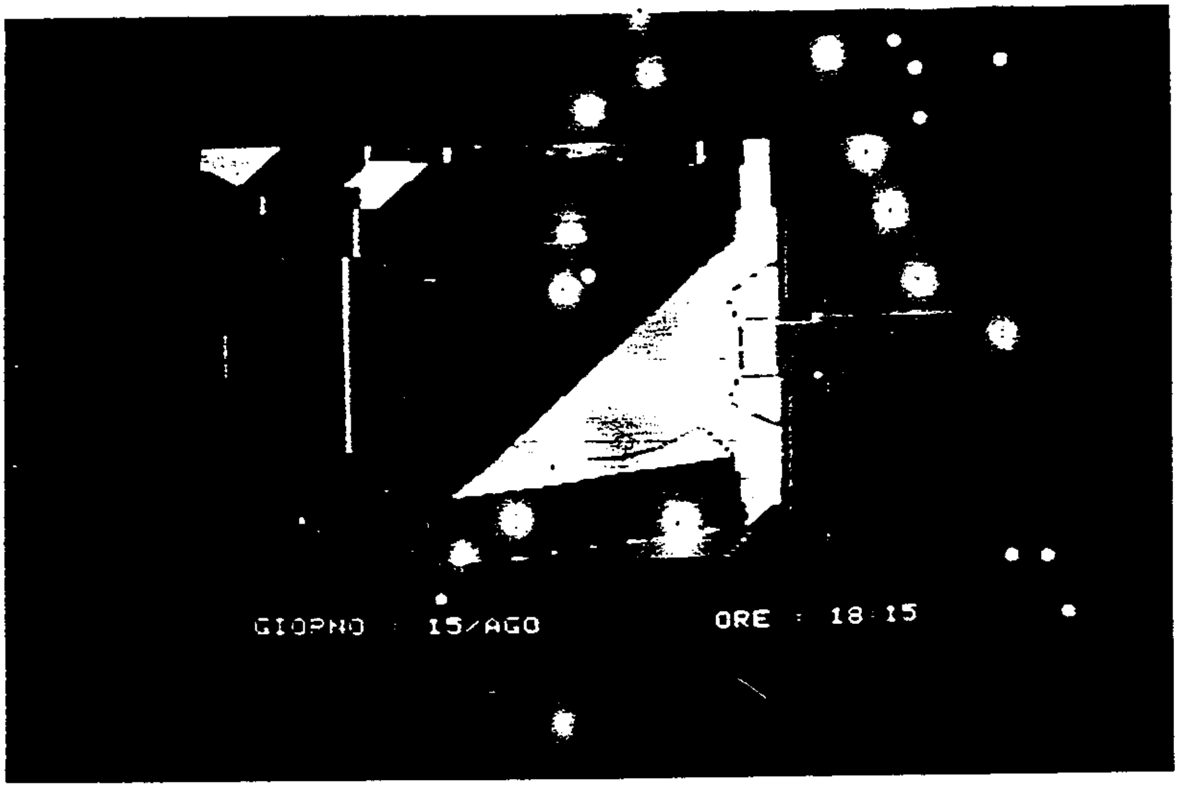

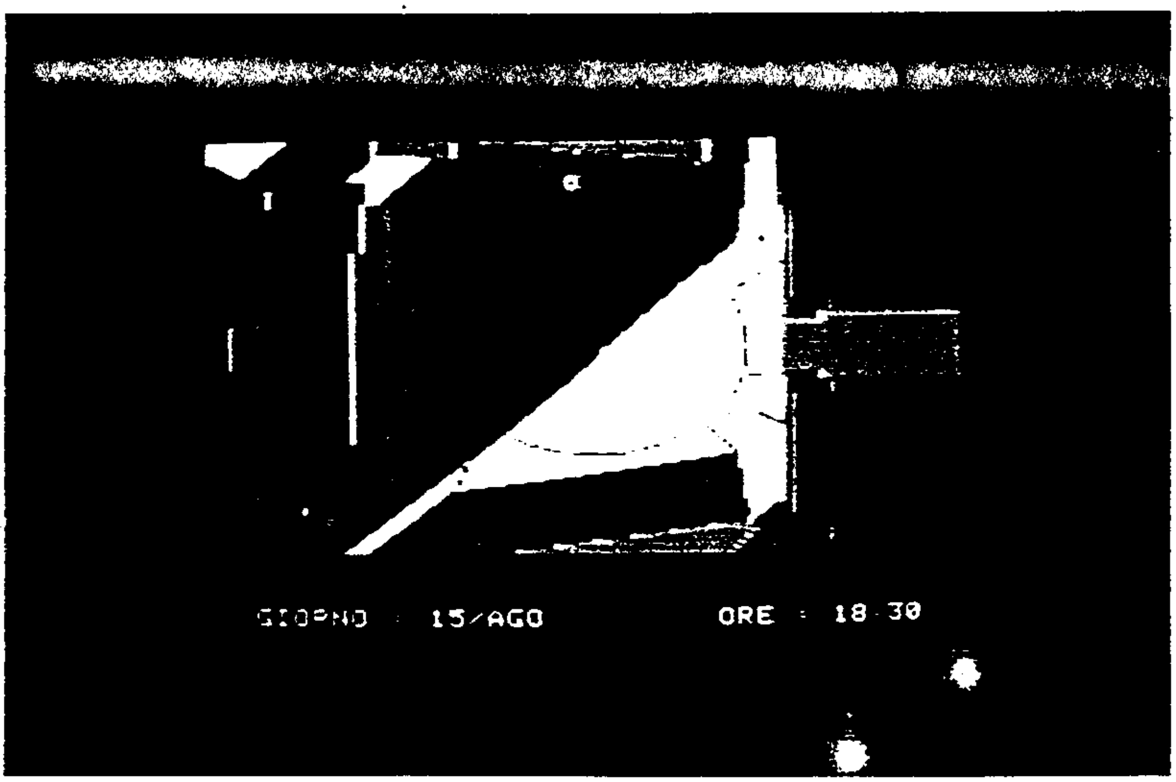

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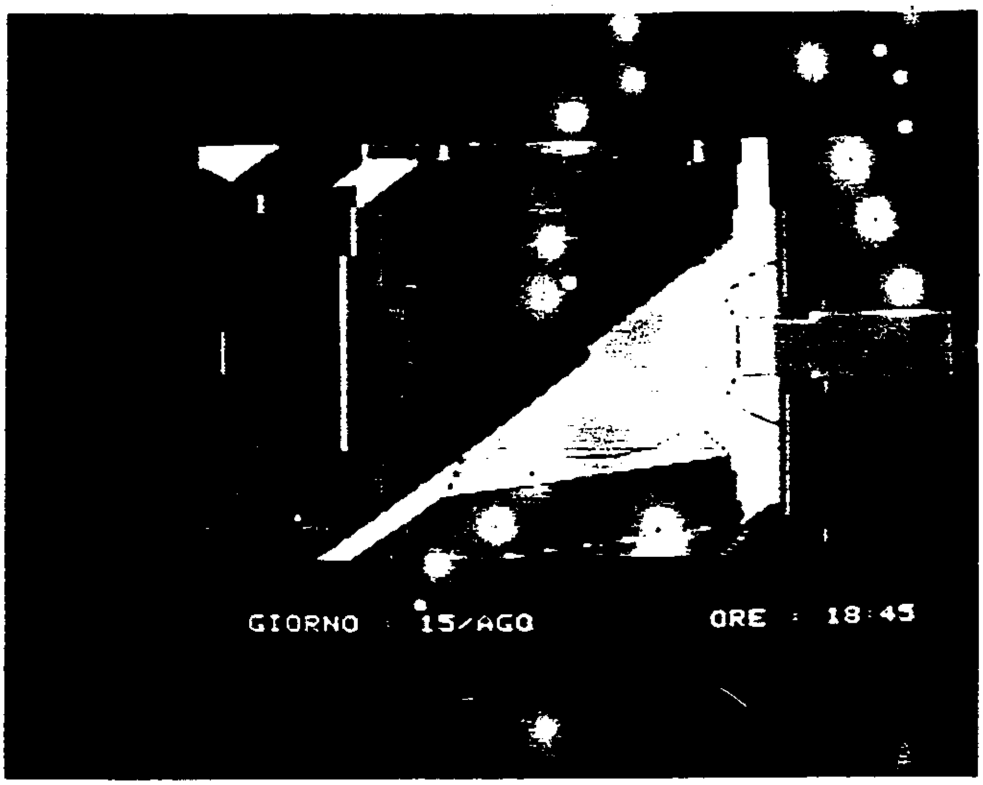
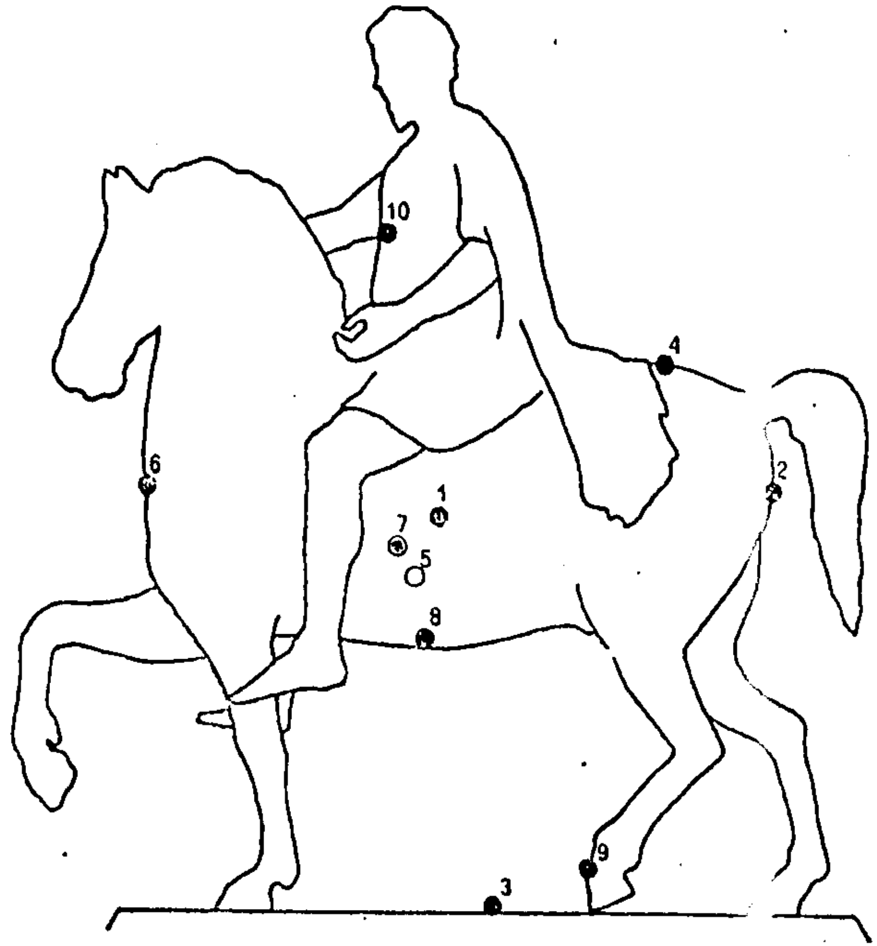


Fig. 2m



Posizione delle termocoppie:

● ◉ : sulla superficie

○ : nell'aria interna

Fig. 3a

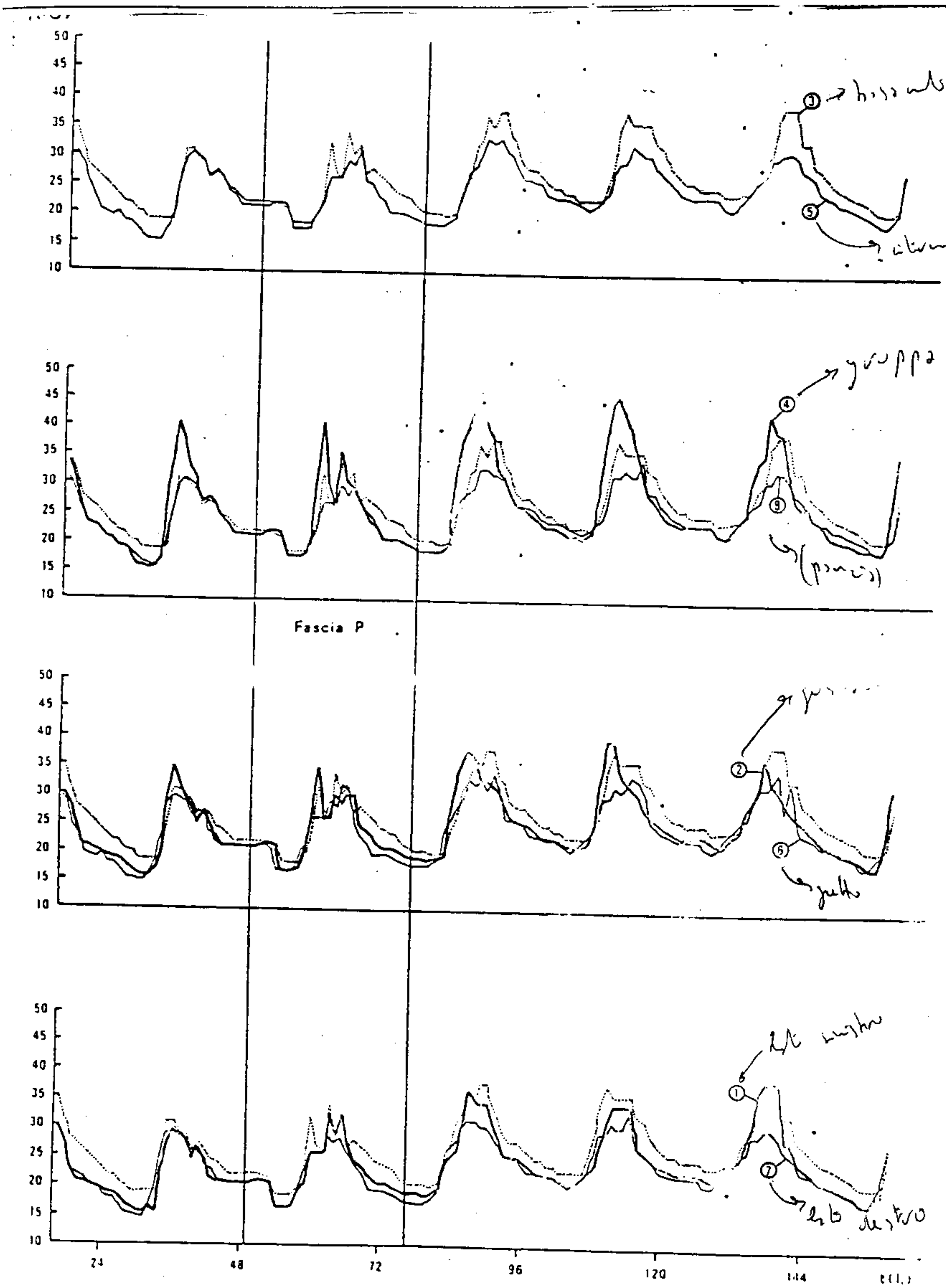


Fig. 3b

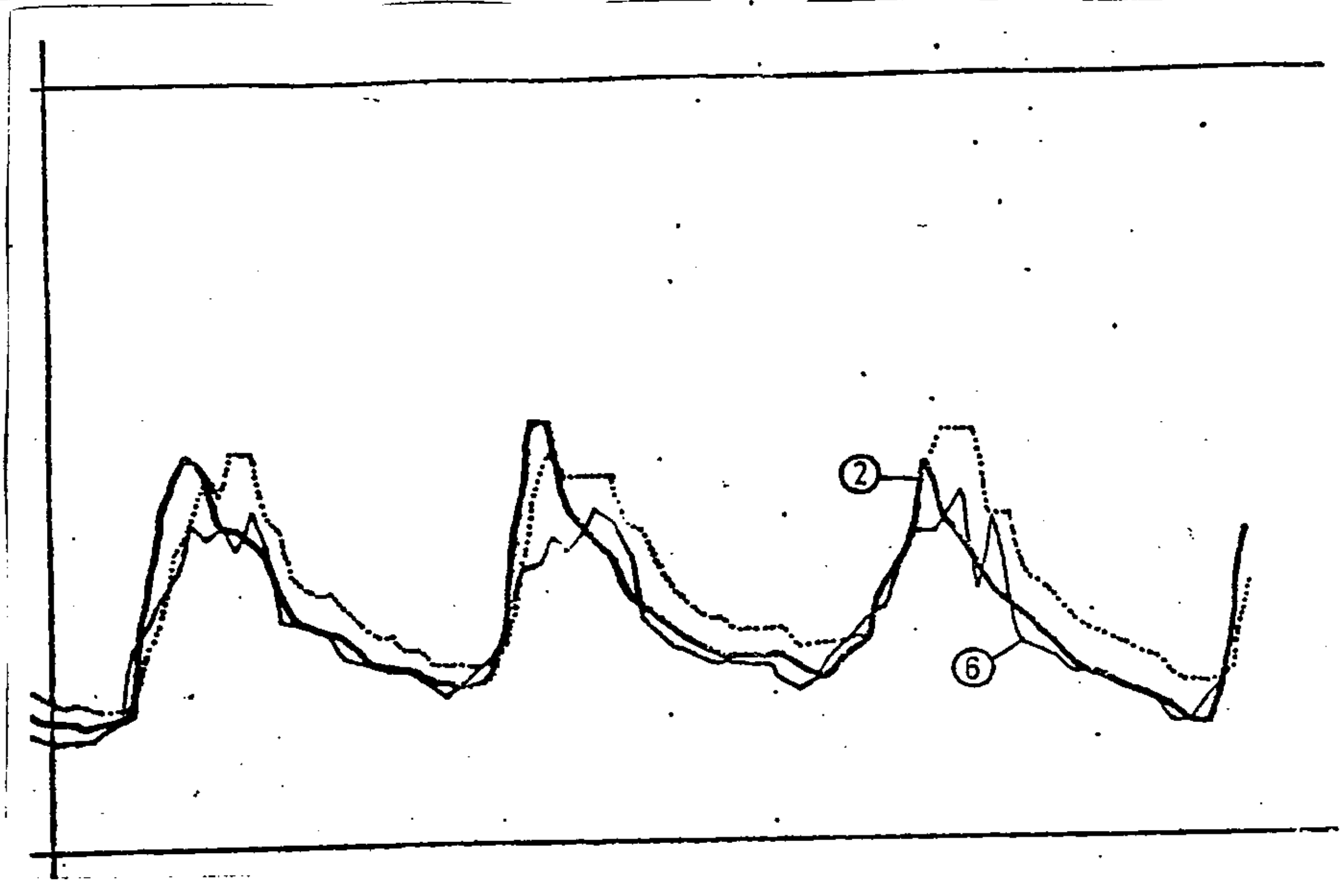


Fig. 3c

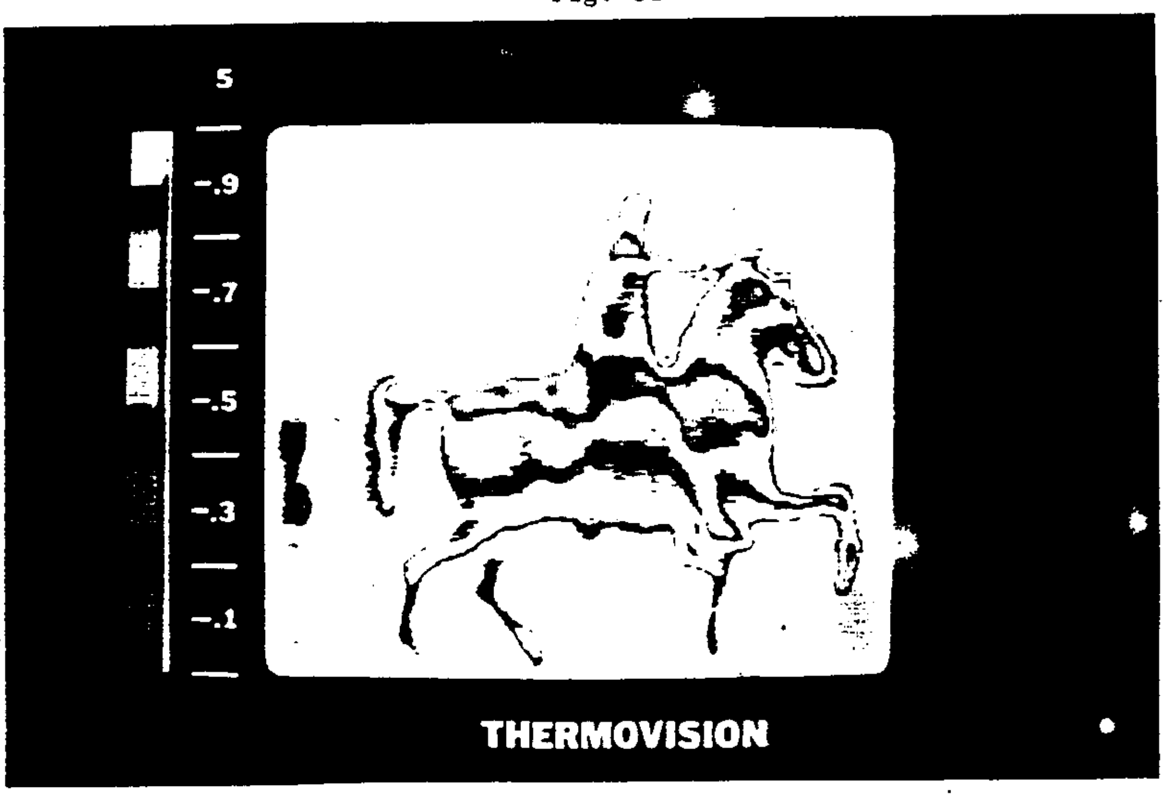


Fig. 4