ROBOT-OPERATED SYSTEMS FOR IN-SERVICE INSPECTION OF COMPONENTS IN VVER NUCLEAR POWER PLANTS

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INTRODUCTION

The demands for shorter component inspection times in nuclear power plants, along with the need to reduce the dose absorbed by the personnel participating in in-service inspections, to increase the quality of such inspections and to examine the most critical components, require the development of new robot-operated equipments.
The equipments here presented have been developed and validated specifically for Russian-designed VVER Plants. They have been qualified on VVER mock-ups and later applied on field. The components suitable of being inpected with these systems are vessels, piping, studs and nuts.

VESSELS

EQUIPMENT FOR THE INSPECTION OF REACTOR VESSELS FROM THE OUTSIDE (RIVER)

The RIVER (Reactor Inspection VVER 1000) inspection equipment has been developed for the ultrasonic inspection from the outside of VVER 1000 type reactor vessels.
Scanning of the entire surface of the vessel is accomplished by means of a sequence of movements provided by two items of equipment: on one hand, the displacements provided by the SK-187 manipulator, wich has two degrees of freedom allowing a stroke of 360° via a rotating table allocated at the lower part of the vessel, on the other hand, a vertical displacement of 4800 mm by means of a telescopic boom.
The equipment can describe the inspection trajectory independently from the manipulator, improving the accuracy and reliability of the acquisition results. And the probes can be displaced both perpendicular and parallel to the weld. (See figure I).

The RIVER inspection equipment is mounted on the SK-187 manipulator and has three degrees of freedom:

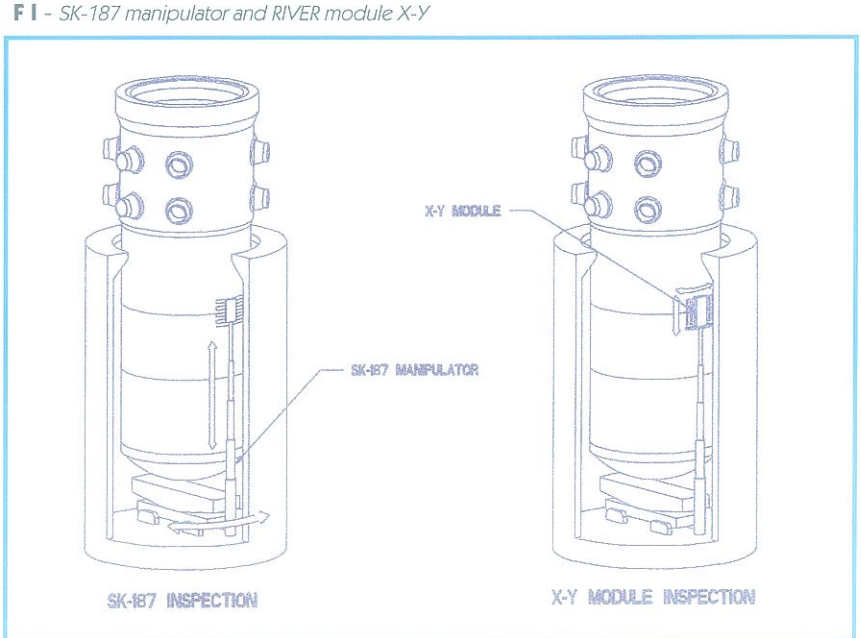
- One rotatory movement of the four probes that can be mounted on an axis equidistant from the probes.
- One 750mm vertical movement of the set of four probes.
- One horizontal movement with a range of 18°, equivalent to a 750 mm displacement on the vessel wall.

This is accomplished such at once the SK-187 manipulator is positioned at a given point, the RIVER allows inspection to be performed over an area of 750 mm x 750 mm. Successive angular and vertical positioning of the SK-187 manipulator allows the entire surface of the vessel to be covered.
The characteristics of the RIVER movements are:

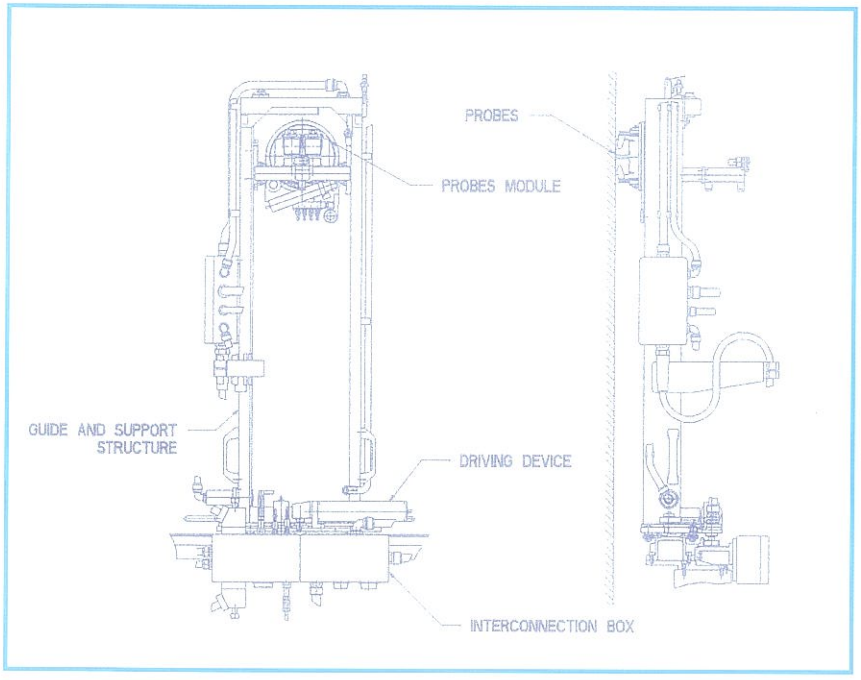
MOVEMENT	RANGE	MAXIMUM SPEED
Rotational axis	370°	9 rev/min
Vertical axis	750 mm	149,1 mm/s
Horizontal axis	18°	95,6 mm/s

It consists of a vertical body and an horizontal base. The vertical body mounts a probe-holding module on a support structure; and the horizontal base is a curved plate on which a carriage is driven. (See figure II).
The probe-holding module has three movements:

F I - *SK-187 manipulator and RIVER module X-Y*



F II - *River main components*



- Vertical movement: the probe-holding module has a vertical displacement of 750 mm along the guides fitted to the vertical structure. For this pupose it has four wheels at each side of the module, two of them eccentrical for the adjustment of the carriage.
- Rotational movement: This movement allows the ultrasonic probes to be rotated throughout 370°. The motion is accomplished by means of a motor and associated gearing. The probes contact the wall of the vessel due to the force of a springs set.
- Probes approximation movement: This movement allows the probes to be separated from the wall of the vessel during assembly operations, and also approximates the inspection equipment to the wall. The probe support device runs along two linear guides with the aid of a pnuematic dual-effect cylinder.

The curved horizontal base incorporates an electromagnetic suction pad at each side of the structure, to prevent the telescopic mast from bowing during inspection. A curved rail is bolted to this structure, running parallel to the wall of the vessel and guiding the movement of the carriage. The transmission of the carriage is accomplished by means of a motor wich moves a toothed pulley allocated on the curved base, via two conic gears. This movement is codified by a pulley rotating simultaneously with the driving motor.

This equipment has been successfully applied in the inspection of Kozloduy NPP reactor vessel (Bulgary). Figure III shows the equipment during Lab. tests.

F III - *RIVER general view*

PIPING

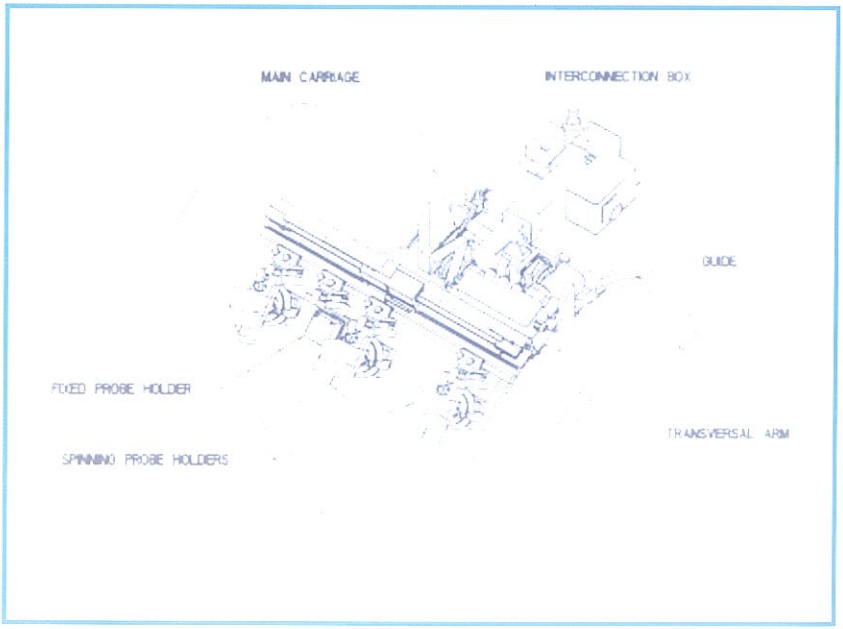
PIPING INSPECTION EQUIPMENT (PIPE)

This ultrasonic equipment is specially designed for detecting and dimensioning stress-corrosion craking in both carbon and stainless steel piping of nuclear power plants. It is composed of a chart attached to the pipe by means of four magnetic wheels that supports an arm capable of displacing four ultrasonic probes. (See figure IV).

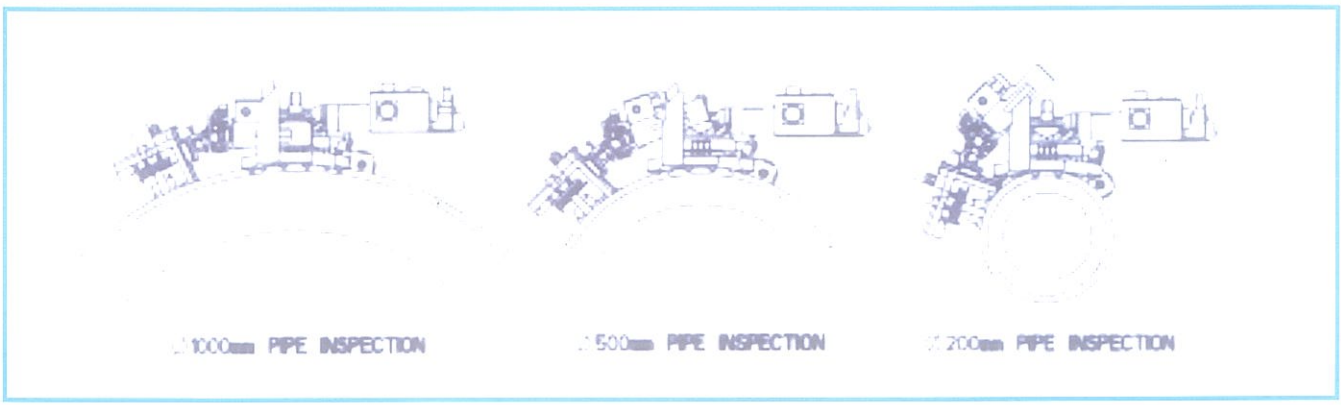
For installing the equipment over an austenitic pipe it is necessary to mount a ferritic sleeve on the pipe, allowing the attachment of the magnetic wheels. The probe holders can be fixed or spinning to allow different acquisition angles, reducing the time necessary to change the position of the probes. All the movements are codified and can be easily operated and programmed.

The equipmnet provides five motor driven and controlled movements, wich can operate simultaneously:

F IV - *Main components of PIPE*



F V - *PIPE mounted on different diameter pipes*



Movement 1: Guided rotation of the equipment around the pipe.
Movement 2:Probe displacement perpendicular to welds.
Movements 3, 4 & 5:Axial rotation of the probes 1, 2 & 3.

Its adjustable support structure and its modular design allow a wide range of pipe diameters for the equipment to be fitted to.The special four magnetic wheel attachment of the main chart to the pipe allows an easy assembly and disassembly of the whole set for each inspection position. (See figure V).

TECHNICAL DATA

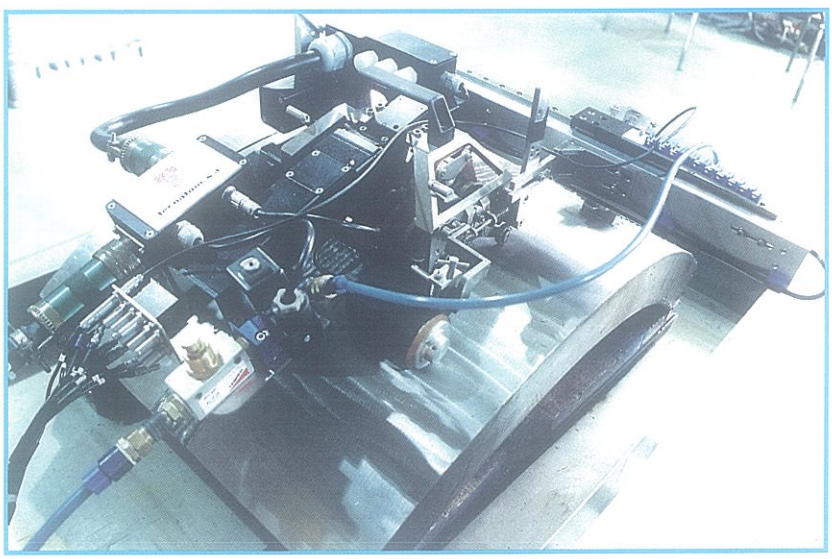
- Weight (with all components mounted): 15kg
- Main materials: Anodized aluminium, steel and stainless steel
- Overall dimensions: 600 mm x 500 mm x 150 mm
- Transversal stroke: 300 mm
- Maximum operating speeds:
  - Longitudinal motion: 10 mm/sec
  - Transversal motion: 60 mm/sec
  - Probes rotation: 10°/sec
- Resolution:
  - Movements 1&2: 0.1 mm
  - Movements 3, 4 & 5: 0.1°

The couplant for the ultrasonic probes is distributed by a portable pump wich can work independently from the plant water supply system , by simply using an intermediate small tank to recycle the water.
The following are some references of this equipment:

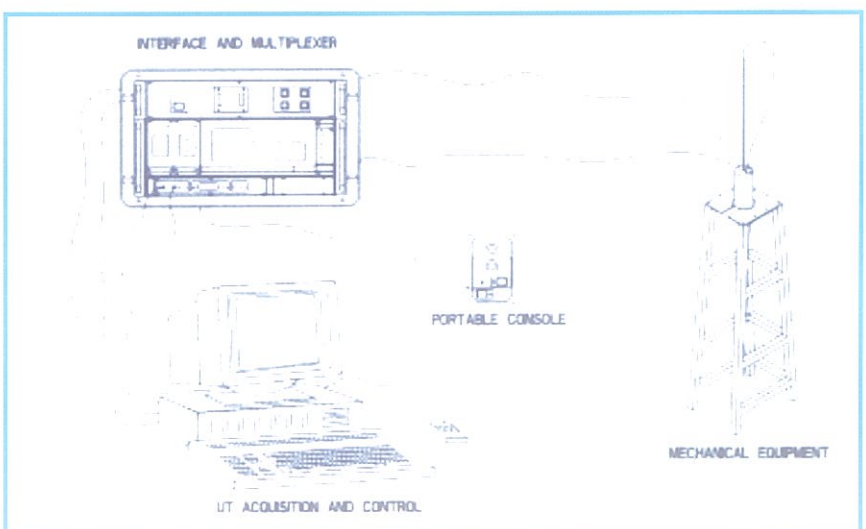
- South Ucrainia (SUK - NPP).
- Techniques qualification in the United States.
- Demonstrations in The Netherlands and Russia.

Figure VI shows this equipment during operation.

F VI - *Real picture from PIPE scanner*



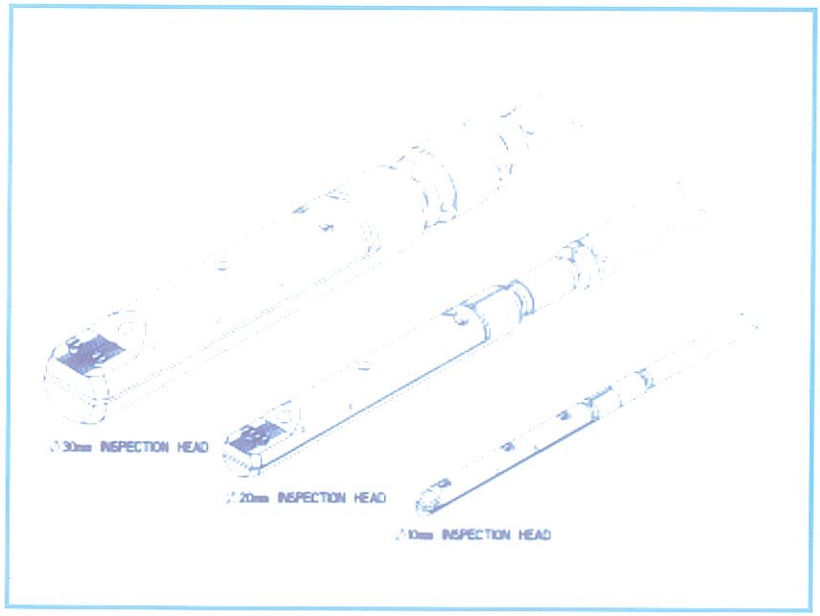
F VII - *SUIP general configuration*



STUDS AND NUTS

Studs such as those mounted on reactor vessels, main pumps, and other components with similar characteristics, are potentially exposed to generate cracking processes due mainly to the stress strain condition during power operation of the plants.
In order to obtain more strict compliance with the applicable standards and a greater reliability of the inspections of these components it has been necessary to design automatic systems for ultrasonic and eddy current inspection of the studs and its nuts.

F VIII - *Different diameter inspection heads.*



EQUIPMENT FOR THE INSPECTION OF CLOSURE BOLTS FROM THE INSIDE (SUIP)

This system has been developed for inspecting, using suitable ultrasonic techniques, the stress-corrosion cracking of the head of the vessel studs. The stud is installed on a pedestal allowing the automated inspection bar to drive the UT probes through its interior. (See figure VII).
The equipment is capable of inspecting studs and shafts from the inside, studs and shafts with end surfaces available for ultrasonic inspection, nuts, threaded zones with flanges, and unions between threaded zones.
The set provides probe heads adaptable to different types of studs. It is possible the inspection of studs with internal diameters between 10 and 35 mm. It is also available to inspect studs with different lengths. (See figure VIII)
The equipment has two motor driven and codified movements, that can operate simultaneously:

Movement 1: Axial displacement (motor driven &codified).
Movement 2: Probes skew (motor driven &codified).

This small sized equipment can be adapted to every stud length. It is very easy to position and operate, and it is protected against operating errors. Handling and transporting is also very easy.
The following are some references of this equipment:

- ANSALDO, italian turbine manufacturer.
- BWR & PWR Spanish Nuclear Power Plants.
- Zaporozhye Nuclear Power Plant.

TECHNICAL DATA

- Weight: 8 kg
- Dimensions of the driving unit: f137 mm x 320 mm
- Main materials: Anodized aluminium, steel and stainless steel
- Maximum operating speeds for controlled movements:
  Movement 1: 25 mm/sec
  Movement 2: 15°/sec
- Resolution:
  Movement 1: 0.1 mm
  Movement 2: 0.1°

EQUIPMENT FOR THE INSPECTION OF CLOSURE BOLTS FROM THE OUTSIDE (PERCI)

This equipment has been developed to perform inspections of studs and nuts screwed and non-screwed areas by eddy current techniques.The stud is supported on a pedestal and rotated while the EC sensors move axialy to inspect its outside smooth and threaded surfaces.(See figure IX).

The system is applicable to reactor vessel and main pumps studs and nuts as well as other components with similar characteristics. By using the appropiate eddy current techniques as an alternative to magnetic particles methods, superficial indications that the plant operation might have caused can be detected thus supervising the structural integrity of this component.

MAIN CHARACTERISTICS

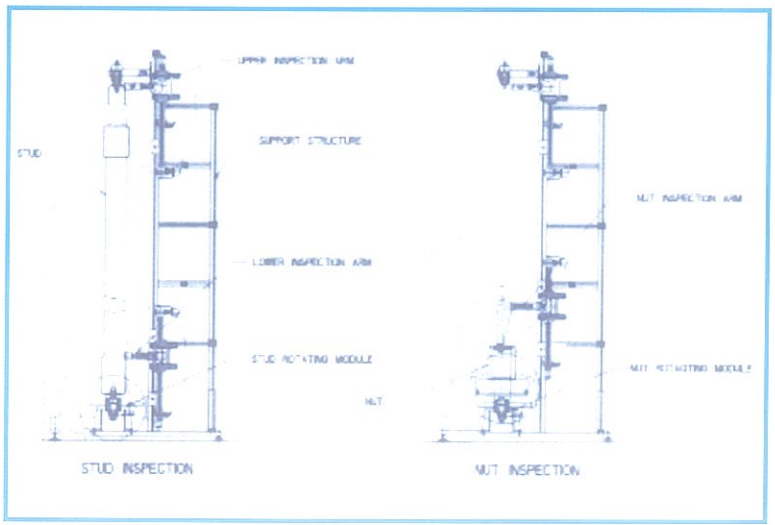
- Stud Weight: up to 500 Kg
- Movements: 4 (1 stud rotation, 3 axial inspection arms)
- Stud Dimensions: up to 2.5 m
- Resolution: Rotation + 0.1°, Axial arms + 0.1 mm

Different sizes studs can be inspected with the same equipment.The modular design of the whole set allows an easy and quick assembly and disassembly of the system. Handling and transportation is very easy too. All this points involve a important reduction in the inspection time. Figure X shows this inspection system.

CONTROLLER FOR MECHANICAL EQUIPMENTS (SIROCO)

SIROCO is a remote control system for special robotized equipments. The control provides the capability to perform trajectories implying sequential and (or) simultaneous movements on any of the axes.
The system has been developed for use in applications in which work is performed under difficult environmental conditions and where operation has to be accomplished

F IX - *View of stud and nut inspection with PERCI*



from a distance (hazardous areas, areas with environmental radiation, etc., ...), and when it is necessary to operate in an easy, flexible and safe manner.

The system runs on a compatible personal computer and may be used with any automated inspection equipment meeting the specified requirements. The system uses a robot definition file to automatically obtain the corresponding parameters, and adapts control to them.

The communications support between the computer and the power interface is a thin optical fibre, as a result of which installation is both easy and fast. Communications are also reliable, since they are not affected by electromagnetic interferences.

This configuration allows the operations and inspection zones to be kept separate. Operations may be accomplished by means of a mouse and graphic screens. The three operational modes (manual, sequential and trajectories) cover a wide range of applications and are highly user friendly.

COMPUTER-BASED DATA ACQUISITION AND ANALYSIS SYSTEM (SUMIAD)

SUMIAD is an extremely flexible UT equipment wich gives you the capacity of performing any kind of UT inspection in a very easy way. From very small parts to huge components, SUMIAD has been intensively tested both in field and in UT lab, offering standard evaluation tools for fast evaluation even for big data files.

There is no need for special training on computers. Its Windows-like environment completely controlled by the mouse has reduced the need of the keyboard to the minimum. working in this way, management of concepts like signals, echoes, gates, scans, etc, is done in a natural way by simply clicking with the mouse on these objects. All electronic parameters are programmable and after a few clicks your calibration and other general settings will be ready for the inspection.

The acquisition and reedition modules (the later is the off-line version of the former) also require no special skill to understand the plots displayed. The REAL POSITION of the data is always displayed, with its real depth, and always considering the exact probe holder disposition and probes angles and orientation.

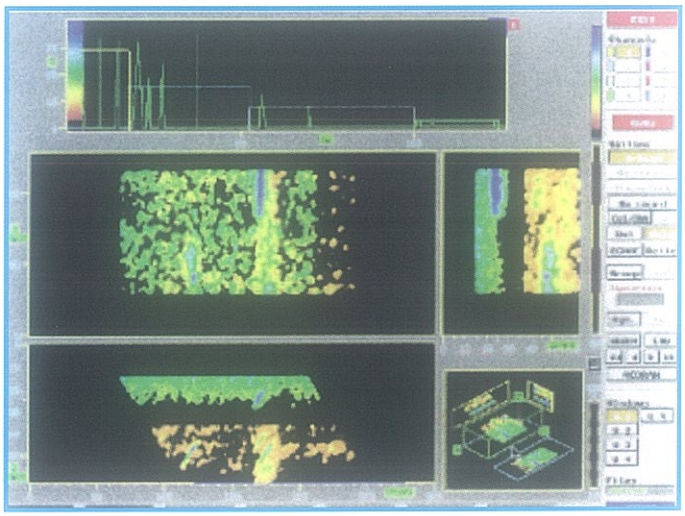
Furthermore, you can define your owbn favourite display mode, mixing in any arbitrary way A-Scan views from different channels or different zoom factors, 2D views (like the standard TOP-SIDE-END views) with one or several channels together, 3D views with your own Point Of View preferences, scrolling windows and machine path windows. Any display mode you can imagine can be generated by this method, from standard simple views to very complex ones used only for special situations.

As a strong difference with other inspection equipments, there is no limitation in the size or precission of the block to be tested, as all data, spatial position is always managed in real units and in floating point arithmetics.

Also, no special scanning path is required to perform the acquisition. Any change of probe position is collected, even if you scan several times the same position. This allows you to perform hand scanning and evaluating in the same way as if you had performed an automated inspection in meander form or in any other (helix, sequence of positions, etc).

Although the characteristics bellow are somewhat independent from the UT instrument, they refer exclusively to the USL MUX-8, a remotely operated multipulser instrument able to deal with linear or logarithmic signals up to 15 Mhz.

F XI - *Example of data acquisition screen*



GENERAL PERFORMANCE

Data Flow:	2000 UT cycles/sec (Depending on the field depth)
Number of Channels:	8
Gates/Echoes per Channel:	1 per channel
Pulser/Preamplifier:	8/128 (16 per gate)
Operating Distance:	Up to 150 meters
Total Gain:	120 dB

Figure XI shows an example of a typical data acquisition screen.

F X - *General view of the stud-nut inspection system*

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He began his professional career working as an expert in the organization of Unión Fenosa's Training Department from 1.977 to 1.979. His first work in Tecnatom when he joined the Company in 1.979 was related to the Mechanized Inspection of Reactor Vessels. In 1.986 he became the Head of Tecnatom Maintenance Department, being the responsible of inspection equipments and systems maintenance. From 1.989 to 1.992 he was incharged of directing and coordinating the Tecnatom's Development of Inspection Equipments and Techniques Groups.