DATA ACQUISITION REAL-TIME SYSTEM FOR THE FAST TESTING TRACK FACILITY OF THE CENTRE OF ROADS' STUDIES OF CEDEX

Jaime Tamarit Rodriguez. Dr. en Ciencias Físicas.
Sector de Técnicas Físicas y Electrónicas.CETA.CEDEX. j.tamarit@cedex.es
José Bueno Pérez. Dr. Ing. Naval.
Sector de Técnicas Físicas y Electrónicas.CETA.CEDEX. j.bueno@cedex.es
Javier Aleixandre Campos. Licenciado en Ciencias Físicas.
Sector de Técnicas Físicas y Electrónicas.CETA.CEDEX. j.aleixandre@cedex.es
Bernardo Mingo Villalobos. Ing. Industrial.
Laboratorio de Instrumentación del CEC.CEDEX. bmingo@cedex.es
Javier Pérez Ayuso. Diplomado en Arquitectura.
Laboratorio de Instrumentación del CEC.CEDEX. jayuso@cedex.es

ABSTRACT: This paper describes the real-time data acquisition system specially developed for this test facility. This system is able to address up to 256 sensors and synchronise the measuring with the test car position. The layout of the system allows an optimal signal to noise ratio.

This communication is complemented with a second one entitled "Installation and Analysis of sensors used in the fast pavements' test track at full scale of the Centre of Roads' studies (CEDEX)".

Keywords: Instrumentation, Data Acquisition Systems, Real time, Microprocessors.

1.- INSTRUMENTATION REQUIREMENTS AND LAYOUT

The track for fast tests of pavements is a complex test facility with several test vehicles running at the same time. The track is of oval shape, formed by two rectilinear and two curved sections. The pavements under test are installed on the two rectilinear segments and are split into six sections, each section with a different pavement configuration. Different kinds of sensors are embedded on the pavement of each section. The readings of these sensors are recorded in synchronisation with the passage of the test vehicles.

On the rectilinear segments, the test vehicles are controlled at constant speed. This control needs to be quite accurate to avoid collisions between different vehicles. The transversal position of the test wheel of each vehicle can be also controlled according to seven different positions.

The vehicles are electrically powered by means of asynchronous motors fed by sliding contacts and controlled through a frequency converters (field oriented control). The control commands are issued by a Programmable Automata which sends the orders through a bus from the centralised control desk.

Embedded in the pavement, different sensors are installed (pressure, stress, strain, deflection, moisture, temperature,…). Each sensor is powered from a signal amplifier placed near the sensor in an underground gallery. The measuring signals, once amplified and filtered, are sent to the centralised data acquisition system, installed in the geometrical centre of the track.

This system is in charge of the digitalisation and recording of the measuring signals coming from the different amplifiers. This recording process is synchronised with the passage of the wheels of test cars.

2. DESCRIPTION OF THE INSTRUMENTATION

The measuring requirements were mainly:

- Measure with high accuracy small variations in magnitude (depending on the type of pavement under test).
- Record in parallel dynamic readings coming from families of sensors (up to 20 by instrumented point).
- Minimise the electronic noise in an environment contaminated by power electronics (running over the sensors) and with sensors installed far away from the signal amplifier (up to 200m).

These requirements have required special care in the lay out design and fitting process of the installation.

As shown in Fig. 1, the low energy signals generated by the sensors distributed along the test track, are driven to the signal amplifiers. Once filtered and amplified the signals are sent to the centre of the track by cable in a differential mode. In the centre of the track the data acquisition system firstly transforms the differential signals to unipolar and then they are multiplexed before being connected to a common A/D converter.

Along the track, 14 position sensors are installed to detect the test vehicle passage. The signals from these sensors are handled by the System and transformed into a narrow pulses with and associated code different for each sensor.

This pulse is used to generate an interruption in the microprocessor in charge of the recording process who recognises the track segment requiring attention thanks to the code associated to each sensor.

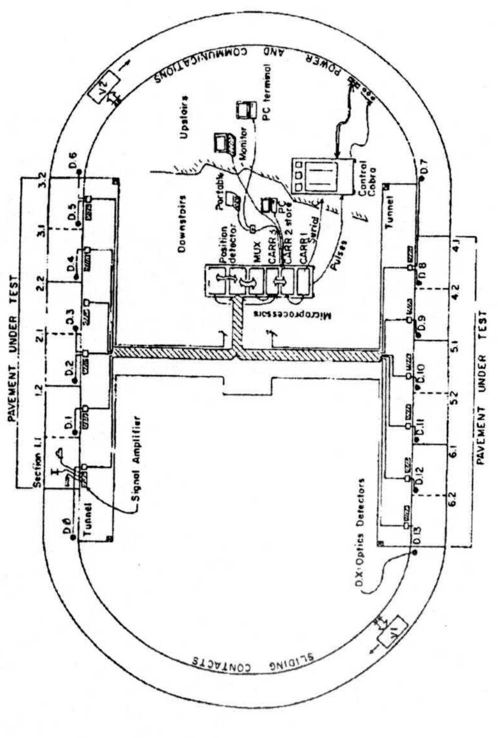

Fig .1: Instrumentation layout

This installation has the following characteristics:

- *Sensor cable*: Screened by pairs and with a common external screen surrounding all the sensor cables of the same family. Minimum diameter, designed to support high temperatures during the installation. Screens connected to earth.
- *Signal amplifier*: Isolated Reference Voltage (0 V), Signal Reference and Global Installation Earth. Chassis connected to Global Installation Earth.
- *Signal transport cable*: A twisted cable with 27 pairs (signal and reference voltage) outs from each instrumented section. Each pair of this cable is independently screened and all the screens are connected together to Earth in the side of the signal amplifiers.
- *Connection to multiplexor and microprocessor*: All differential mode floating signals are referenced to the reference voltage of the microprocessors system and so transformed into unipolar signals.

3. THE SYSTEM MICROPROCESSORS.

The control and data acquisition systems are constituted by three 8088 coupled microprocessors. All standard electronic boards are from the Siemens family connected via SMP bus (see Fig. 2).

The first microprocessor (Carr 1) is devoted to the control of the transversal position of the test vehicles. This microprocessor is able to control this transversal position in such way that each test wheel follows an statistical distribution of passages across the test track. This distribution can be programmed by the user.

This microprocessor is in charge of the accounting of the number of passages of each test vehicle by each transversal position. It also measures the time required to complete one cycle along the test track. This microprocessor also is in charge of positioning each test vehicle on a pre-determined transversal position for test purposes. The tests can be programmed to start by time or by number of cycles. When this micro has positioned the test car, it is also in charge to trigger the measuring process, controlled by a second microprocessor (Carr 2).

This second microprocessor is in charge of the programming of the dynamic tests (Collection of sensors to be read at the test car passage by the instrumented point). The relationship between the different programmed positions (in charge of Carr 1) and dynamic tests with families of sensors (in charge of Carr 2), is established by means of a two-dimensional matrix, with two inputs.

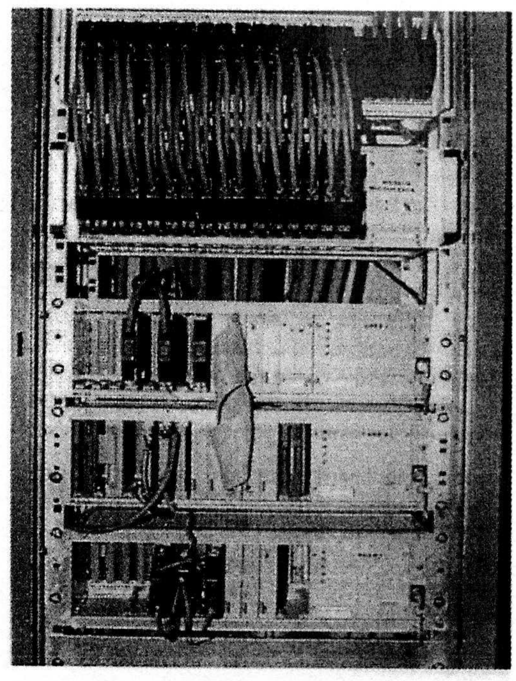

Fig. 2: Microprocessors layout

Both microprocessors (Carr 1 & Carr 2) are connected via serial link RS-232. Through this link the first microprocessor interrupts the second one asking to start a dynamic test. Packed with the interruption message, the first microprocessor sends the status of the test vehicles (programmed speed, transversal position of each car, test vehicle triggering the dynamic test, alarms switched on each vehicle...). In addition to this, this microprocessor Carr 2, is in charge of the management of all system communications. All commands are received through it.

Apart from the commands specific of this microprocessor, there are commands to program the Data Acquisition System, commands to manage the Sensor Data Base, commands for sensors' calibration, commands to manage the data base of dynamic tests, commands for specific tests...etc.

The third microprocessor, Carr 3, is properly in char of the accomplishment of all measuring processes. This microprocessor is warned by Carr 2 about the necessity of starting a new measuring process. It receives from Carr 2 the list of sensors to be read, it sorts the list and performs one reading every 5 cm. of test car displacement (This microprocessor measures the real speed of the cars during the previous cycle and performs a self-programming of one channel of the interruption controller according to the speed). The measuring process corresponding to the programmed dynamical test is then started in synchronisation with the passage of the test vehicle by a position detector. This detector is able to generate an interruption to trigger the programmed test. All readings are transmitted to Carr 2 via dual port RAM coupling both microprocessors. Carr 2, in charge of the communications management, sends all data concerning the accomplished test to a PC via serial link and from this PC all data are distributed across the CEDEX network via Local Area Network.

The use of powerful programmable counters triggered by the position detectors, allows this third microprocessor Carr 3 to generate interruptions with frequency proportional to the test car speed. The reliability and accuracy of this process are extremely high.

In next paragraph the structure of this measuring process carried out by this third microprocessor is exposed in detail.

4. CONFIGURATION OF THE MEASURING MICROPROCESSOR (CARR 3)

Fig. 3 shows the scheme of the microprocessor in charge of the measuring process (Carr 3). This microprocessor is constituted by the following standard boards of the Siemens SMP family:

SMP-E17_A8: CPU board with 8088 microprocessor at 8 MHz.

SMP-E128: 128 Kbytes of EPROM memory. This memory is used to store the main program. The board is configured with 32 Kbytes of RAM memory for the storage of dynamic variables.

SMP-150: Dual port RAM memory with 4 Kbytes of memory used to couple this microprocessor to Carr 2.

SMP-E118: 256 Kbytes of RAM memory. Used to store the sensor readings during dynamical tests.

SMP-E200: Parallel Digital Input / Output board at TTL levels based on the 8255 chip. This board is used to read the code corresponding to each position detector it is also used to address the multiplexor of measuring channels.

SMP-E230: Analog to Digital 12 bits converter board. Maximum sampling frequency of 32 KHz.

SMP-E303: Interrupt controller based on AM9519 chip. This board also contains two AM9513 chips with programmable counters. The counters and the interruption channels are interconnected.

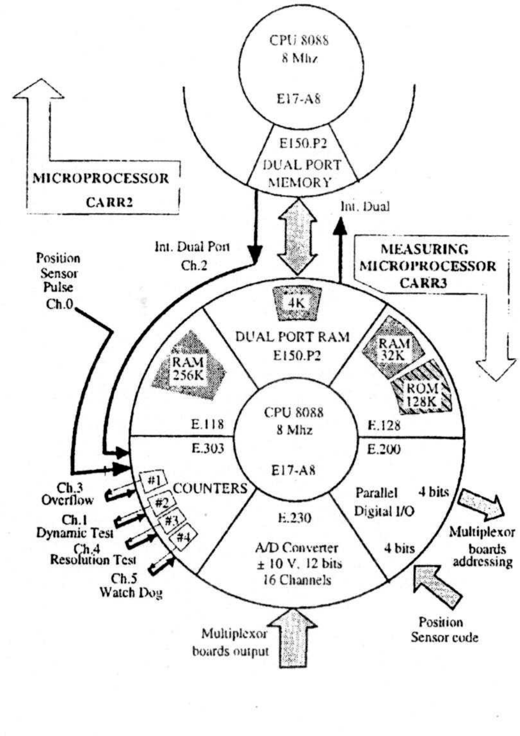

Fig.3: Configuration of Carr 3 microprocessor

The interruption channels are used with the following purposes:

Ch 0: Position detectors.

Ch 1: Connected to the output of the programmable Counter n°2 to control the sampling frequency of dynamic tests.

Ch 2: Interruption generated by the Dual Port Memory board on communication request.

Ch 3: Devoted to overflow detection when measuring speed. Generated by the output of Counter n°1.

Ch 4: Connected to the output of the programmable Counter n°3 to control the sampling frequency of high resolution dynamic tests.

Ch 5: Watch dog used to unlock the processor when waiting for an interruption.

The Counters are used with the following purposes:

Counter 1: Measuring of the time between the passage of the test car by consecutive position detectors. Overflow detection (test car stopped).

Counter 2: Used for the generation of interrupts every 5 Cm during dynamic tests.

Counter 3: Generation of the high sampling speed (10.000 samples / sec.) during the high resolution tests.

Counter 4: Generation of Watch Dog interruption (in case of no interruption after 90 seconds).

5. PROGRAM AND DATA STRUCTURES

5.1 Program structure.

The control program is split into blocs. The blocs are:

Low level routines controlling the basic functions of the system (hardware), usually developed in Assembler to allow low execution time (vital for interruption routines) and control of physical devices. These routines control the dual port RAM, programmable counters, calculation of speeds and associated sampling frequencies, interrupts attention, reading of Analog channels, multiplexor addressing... etc.

High level programs, developed in Pascal mainly for the calculation of dynamic parameters, units conversion, preparation of messages containing test results, control of program flow... etc.

Intermediate routines for the connection of low level and high level routines. The routines of this level are usually minded to transform the low level assembler routines in Pascal procedures easiest to handle.

5.2 Data structure.

In order to manipulate variables and data in an easy way, multiple structures have been defined. These structures allow the access to each field from high level procedures. For example, the sensors data base is constituted by an array of structures with the following fields:

```
Sensor = record
        Name: array (1..6) of char;
        Active: char;
        Board: char;
        Channel: char;
        Zero: real;
        Slope: real;
        Regression: real,
        Units: array (1..6) of char;
        Section: byte;
        Ret:unsigned_16;
        Creat_date: unsigned_16;
        Mod_date: unsigned_16;
    end;
```

This structure allows the storage of all necessary information required by the System to identify each sensor, the section in which is installed, how to address it, its calibrations parameters, measuring units, activation status and data corresponding to its creation or last calibration. The activation field allows to program the activation and de-activation of sensors by the user without hardware modifications.

The system includes powerful calibration routines developed along years of experience. These routines allow the calibration of sensors in situ with all the measuring chain connected (sensor, cables, amplifier, filters, multiplexor and A/D converter). The calibration routines update the fields of the calibrated sensor in the data base, stored in RAM. They also back up the data base in the system discs after each modification.

6. MAIN CHARACTERISTICS

The characteristics of the main system components are the following:

♦ Programmable counters and Interruption controllers

These devices are of main importance in real time systems. Its control and interactions allow to implement complex functions with high resolution and reliability. An example of it is the programming of dynamic sampling periods in function of vehicle speed or the synchronisation of measuring processes with the position of the test car.

As an example, the Counter 3 is used to measure the time required by the test car to transit from one position detector to the contiguous one. As the distance between two sensors is known by the system, this allows the precise measuring of the mean speed of the test vehicle while transiting each track segment so as the estimation of the acceleration. This is performed by programming a 16 bits counter to count internal pulses of 3 KHz frequency. This counter is read each time the test vehicle passes in front of a position detector provoking an interruption. The routine answering to this interruption reads and resets the counter. In this way the counts between two sensors are obtained and stored.

The generation of interruptions every 5 cm is an other clear example of this real time application. This function is performed by using the programmable counter 2 with a fixed input frequency and running as frequency divider with the divider factor inversely proportional to the vehicle speed, measured in the previous cycle.

♦ Dual Port Memory

The two microprocessors in charge of the control of the communication (Carr 2) and measuring processes (Carr 3) are tightly coupled by means of a dual port RAM. This allows a very fast transfer of information after the accomplishment of a dynamic tests.

This memory is mapped in the memory of Carr 2. When Carr 2 needs to send information to Carr 3, it puts the information in the dual port RAM and sends an interruption to Carr 3. The interruption routine in Carr 3 asks for authorisation to access the common memory, reads it and accomplishes the tasks required by Carr 2.

This communication process is symmetrical when Carr 2 needs to read the common memory after a request from Carr 3.

- Measuring process.

For the multiplexing of the measuring channels, an electronic module has been designed. This module is constituted by 16 boards each board able to connect 16 measuring channels through a common multiplexor, as shown in Fig. 4.

The output of the Multiplexor of each board is connected to a different channel of the A/D converter board controlled and addressed by Carr 3 (SMP-E230, see paragraph 4). This allows to read the 16 outputs from the multiplexor module. Four output bits of the digital I/O board controlled by the same processor (SMP-E200, see paragraph 4), allow to address the 16 internal channels inside each one of the 16 multiplexor boards.

This configuration allows to address up to 256 (16 x 16) measuring channels. Each sensor is addressed by means of the use of two bytes. The first byte (0..15) is used to point to the channel inside the corresponding board of the multiplexor module. The second byte (0..15) is used to point to the input channel in the A/D converter.

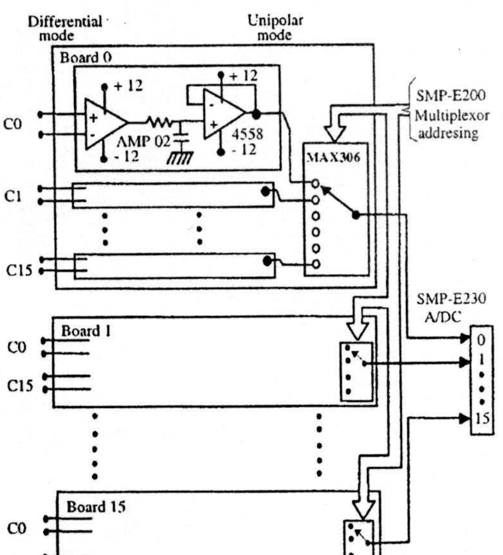

Fig.4: Diagram of the multiplexor modules

The co-operation between the processors Carr 2 and Carr 3 to read one sensor is as follows: Carr 2 asks to Carr 3 to measure one sensor by transferring to the dual port RAM the sensor code, its channel and board numbers. Carr 3 reads the information and addresses the sensor by selecting one A/D channel (4 bits) and addressing one measuring channel (4 bits) in all multiplexor boards. Once the A/D and measuring channels have been addressed, the microprocessor Carr 3 waits during 10 micro seconds to allow the multiplexor and converter to settle.

7. AUTOMATIC PROCESSING OF DYNAMIC TESTS

The automatisation of the facility for fast testing of pavements allows the continuous and cyclic function of the test vehicles at the programmed speed by the programmed transversal track. At the same time the dynamic test are managed under program control in a fully automatic way.

This allows to generate sensors information when the test vehicles have accomplished a pre-defined number of cycles or after some pre-defined time-lapse has extinguished. The sensor readings are taken when the test vehicle is passing by the instrumented point. In this way, the sensor readings and the test vehicle position can be correlated.

The execution of a dynamic test is an interrupt driven process in which all the three microprocessors participate.

The process starts with the execution of a programmed vehicle positioning procedure. This procedure is started by the cycle counter if the dynamic test is programmed by cycles or is started by the time board of Carr 1, if it is programmed by time.

Once the test vehicles are on the programmed position and the processor in charge of the control of this process (Carr 1) has tested the correct position of the vehicles, this processor sends one interruption to the second processor, Carr 2, with an associated message containing the information required about the test vehicles.

The Carr 2 processor, associates a dynamic test to the position process. The dynamic test is identified through a two dimensional matrix associating positioning processes and dynamic tests. Each dynamic test has an associated family of sensors to be measured by the third processor, Carr 3.

Carr 2 places the information and addressing codes of the desired family of sensors in the dual port RAM shared with the third processor, Carr 3, starting in this way the measuring process.

The processors Carr 3 creates sorted tables with the sensors of the same instrumented point. It programmes the counter generating one interruption every 5 cm of displacement of the test car. This processor intends to organise the dynamic test to be performed in a single cycle.

As shown in Fig., 5 this third processor records all events occurred during the test as the failures of the position sensors, medium speed of the car during the test.

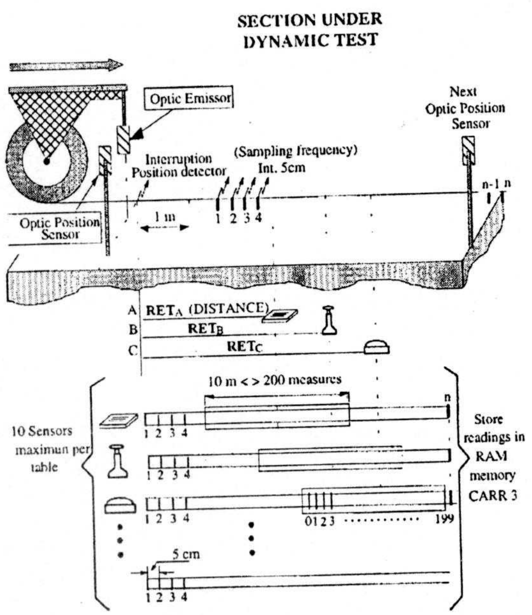

Fig.5: Organisation of a dynamic test

Once the measuring process is finished, the third processor transfers the results to the second one through the dual port RAM coupling both. The test result consist mainly on 200 measures by sensor centred on the sensor. 200 measures every 5 cm are equivalent to 10 m of displacement of the vehicle. In addition to this a fix set of sensors is always measured and added to the list of results. These additional sensors heading all test results are those corresponding to temperatures and phreatic levels along the test track.

The second processor, Carr2 reads from the common memory the test results and sends them to a PC. In this PC a resident communication program written in Assembler receives all the data and stores it in the hard disk by creating a file with the name equal to the number of cycles of the test vehicle. From this PC the data acquisition system is connected to the Local Area Network of the Centre of Roads Studies.

8. CONCLUSIONS

The Data Acquisition System of the fast test of pavements facility is a complex system which has been running by years with high degree of reliability, providing measures in real time with great resolution and generating a highly valuable information.

All this information remains stored in the mainframe of the Centre of Roads Studies and allows numerous studies, we can mention:

- Evolution of different kinds of pavements along the time.
- Characterisation of different pavements under test by means of the determination parameters defining its behaviour. These parameters are determined experimentally at real scale and constitute an important input for modelling, simulation and analysis programs.
- The test results allow to analyse the behaviour of different kinds of pavements under different conditions of load, speed, temperature, footprint...etc.
- The accumulated experience allows to select the most adequate sensor to measure each magnitude.
- The test results are checked against field data.

It should be now convenient to upgrade the system with the microprocessors of the last generation. This probably could allow to share the three responsibilities between different real time processes running in the same processor. The PC could be an industrial system connected to the same SMP bus.

9. REFERENCES

[1] *Instrumentación de la pista de ensayos acelerados de firmes del Centro de Estudios de Carreteras.* CEDEX. Tomo I y II, 1996.

[2] *Technical Description of Microcomputer Board System and Programmer's Reference Manual 8088 and 8087.* Siemens,1985.

[3]Uffenbeck.*The 8086/8088 Family. Design, programming, and interfacing*, Prentice-Hall,1987.

[4]Uffenbeck.*Microcomputers and Microprocessors. The 8080,8085 and Z-80*, Prentice-Hall,1985.

[5]Kerninghan. *The C Programming Language*, Prentice-Hall,1985.

[6]Boylestad&Nashelsky.*Electronics:A survey*.Prentice-Hall International,1989.

[7]Peyton and Walsh. *Analog Electronics with Op.Amps.* Cambridge University Press, 1993.

[8]Figliola and Beasley. *Theory and design for mechanical meausurements*, John Wiley&Sons, 1995.

[9] John Dunnicliff. *Geotechnical instrumentation for monitoring field performance*, John Wiley&Sons,1988.