Hestia station — second generation traffic classification and weigh-in-motion using piezo-electric sensors

C. MAEDER, M. NICOLLE and A. BOUGHABA, Electronique Controle Mesure Inc., France

1. HISTORY

Since 1972, industrial and university research has been undertaken in France into the manufacture of piezo electric effect cables and their use in the road traffic sector.

Since 1976, research has been undertaken to allow the industrial development of products destined for detailed road traffic analysis.

In 1980, the latter allowed the creation of the first stations and in 1984 the creation of the first piezo electric sensor dynamic weighing systems.

Since 1988, decisive new progress regarding the feasibility of sensors has been accomplished.

Equally since 1988, a second generation of station has been developed, based on the latest signal analysis concepts, automatic calibration and multi-microprocessor dialogue.

2. PIEZO ELECTRIC SENSORS AND THEIR USE.

2.1. Piezo electric materials and their forms

Two main families of materials can be made piezo electric by polarisation.

. certain types of ceramic
. certain types of PVDF

These materials can take different forms:

. backed cermaic disks used in the measurement of static weights or as ultrasonic generators
. wafers or films
. coaxial cables

We are interested solely in the second and third types which can be used in the road traffic sector.

The piezo electric effect has, like all electromechanical effects, a three dimensional character which must he taken into consideration in all application.

We remind you simply of the following principales.

When a first piezo electric element is subjected to a pressure from one of the direction X, Y or Z, it gives signals of different amplitude for the same stress.

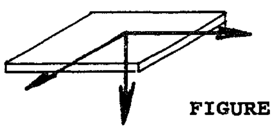

FIGURE 1

One can immediately understand the problems which can be met, particularly in the construction of road sensors, if it is required to undertake the measurement of the dynamic effects of vehicles.

The short explanation above also shows the difficulty in achieving a "fixed" road surface sensor. This being due to the effect of wheter the passage of the vehicle is rectilinear or not (figure 2).

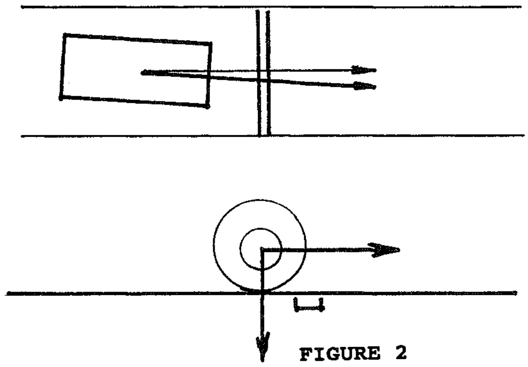

FIGURE 2

If a ceramic or PVDF material type coaxial material type coaxial cable is considered, and it is subjected to an equally distributed pressure variation, the signal obtained is described by the formula below:

$$V = k\Delta p \, \frac{1}{L} \, \frac{C}{C + Cm} \, e^{-t/\tau} \quad \text{where } \tau : \frac{C + Cm}{X + Xm}$$

Cm and Xm respectively represent the capacity and the conductance of the measuring circuit.

τ represents the time constant of this system

k represents the average coefficient to a given specific sensor

As a result of this formula it is to be noted that:

1/ the dispositif represents a DYNAMIC SENSOR:

2/ $\Delta P \, \frac{1}{L}$ represents the DYNAMIC WEIGHT of the axle and takes into consideration both the load and the speed factors

It is, however, clear that like the wafer mentioned above, the effects due to the traction or to compression and also to cable deformations will create signals either interfering with of beneficial to the application under consideration.

The short description above has, as its sole object, to focus attention upon the complexity of the problem and the necessity to adapt the shape of the sensor, the materials used, its casing and its fitting to the type of application envisaged. The lifespan of the sensors on the roadway is a another problem but is linked to the first.

2.2. The sensors

Since 1980, more than 5,000 sensors have been installed in France. We quote characteristics and installation according to the type of application.

2.2.1. Post classification at motorway tolls

The role of the sensor is to count the axles or the wheels at speeds greater than 2km/h. The support is generally in concrete. The restraints imposed by acceleration and deceleration are considerable. The risks of support vibration transmission are equally important. The figure below shows the sensor ground plan and configuration (10).

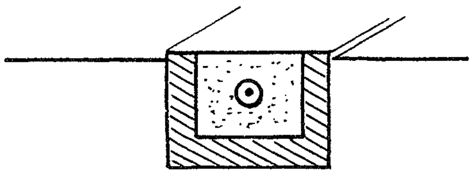

FIGURE 3

The lifespan of such sensors is in the order of 4 to 5 years in lanes subjected to traffic levels in the order of 2,000 vehicles per day, being around 3 million vehicles and 10,000 million axles.

2.2.2. LV/HGV counting and classification

The role of the sensor is to count the axles and class them in two weight categories. It will be associated with a second sensor for speed measurement and a loop for category counting. The sensitive element is a ceramic coaxial type.

Its fitting can take one of the two forms below (10) (fig.4a and b); the first when it is installad jointly in traffic lanes carrying out dynamic weighing, and secondly on its own.

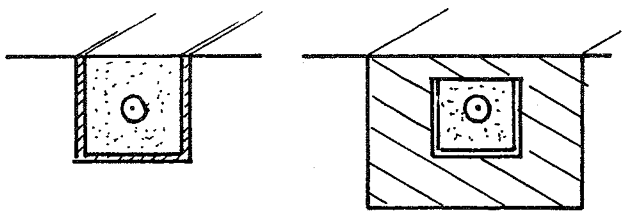

FIGURE 4

The lifespan of such sensors is linked to that of the roadway; it is in the order of 4 to 5 years for trunkroad type traffic.

2.2.3. Dynamic weighing

The role of the sensor is to provide an as accurate as possible representation of the dynamic effect of axle passage.

The figure below represents the type of sensor and its ground plan on the roadway (10.8)

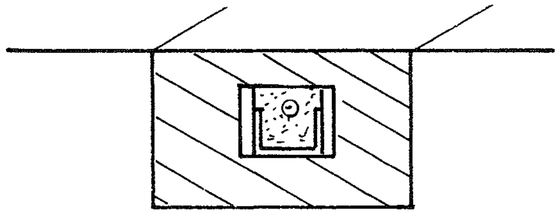

FIGURE 5

It is clear that the roadway plays an important role, not in the quality of the measurement but in the measurement itself.

At the present time, the evolution of sensor fitting techniques allows us to state that only one sensor installed during the last three years has been damaged (150 installed following this techniques).

2.2.4. Temporary speed measurement and counting.

The role of the sensor is axle detection and its classification in two weight categories.

It uses a flat PVDF materiel type element.

The lifespan is essentially due to fast fitting techniques.

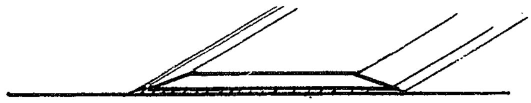

FIGURE 6

3. SECOND GENERATION OF TRAFFIC ANALYSIS AND DYNAMIC WEIGHING SYSTEM

3.1. Layout of the sensors on the ground

As is shown in photograph 1, we use an induction loop and two type E piezo electric sensors (8-10-12-14) per traffic lane. They are laid out as shown in the figure hereafter

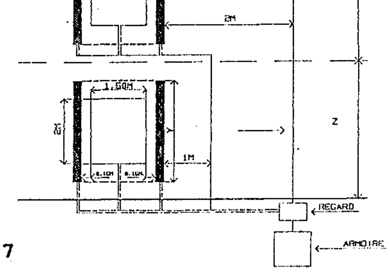

FIGURE 7

3.2. General structure of the HESTIA station

Our choice is determined by three criteria which have appeared indispensable to us since 1988:

- an intelligent detector per traffic lane determines the measurements of each vehicle
- a central unit manages the intelligent detector data to process it according to the requirements of the customer and to communicate with the outside world.
- usage of a standard European format.

The structure of the HESTIA Station is illustrated in the figure hereafter.

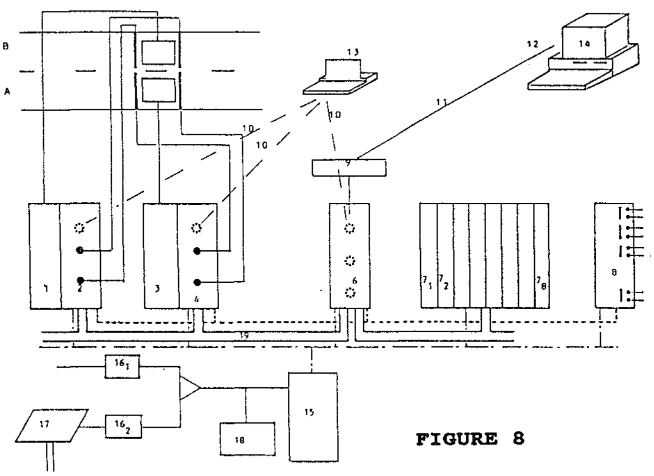

FIGURE 8

The DU HESTIA detectors (2 and 4) receive the information:

- from lanes A and B piezo electric sensors
- from loop detectors (1 and 3) associated with the loops.

Furthermore, each detector receives information termed anti-coincidence from the lane located to its right.

For each vehicle that passes in lane A, the DU HESTIA detector (4) will produce the information shown in table 1 and 2.

This data can, depending on the choice of the user, be sent by serial link to an external computer (13) following the TEDI protocol or to a central unit via the back panel bus.

The RS232 serial link, whose connector is located on the front panel, allows communication with the detector. This can be carried out either by using command words or by using the drop down menu ECoM software.

The DU/UC dialogue is carried out on the bus by interruption management with a token exchange system in order to avoid any data collisions and to allow a very high flow. Simulation trials carried out show that four vehicles, each of five axles, passing simultaneously on four different lanes, are handled by the system with non perceptable shifting.

The central unit (6) will allow dialogue qith:

* the 8 lane detectors which the station can accept
* the external memories (7/1 to 7/8) made up of 1 to cards each of 1 Megabytes protected by lithium cells.
* the "ALARM" card (8)
* the outside world by means of RS232 links

The central unit is the only one to be equipped with a "real time" clock with battery protection.

Each detector and also the C.U. are driven by a 16 bit CMOS 80C186 microprocessor.

The electrical supply for all the electronics is provided by DC/DC convertors (15) with electrical voltage decoupling and integrated smoothing from a load 85Ah battery.

Battery charging can be carried out from a 220 or 115V 50 or 60Hz mains supply (17 and 16.2) or a 880 x 445 x 36mm solar panel (16.1);

300 to 9600 baud modems can be used to communicate with the outside world by specialised line as well as by switching network.

To conclude the general organisation of the station, it should be noted that it can be presented in two forms as shown in photographs 2 and 3.

- 8 lane 8 Megabyte maximul double cased fixed system
- 2 lane 5 Megabyte maximum mobile system.

3.3. HESTIA DU detector

The electronic card structure is shown in Fig.3. Each detector is composed of two cards

- 4 layer digital card
- 2 layer analogue card

and is driven by a 16 bit CMOS 80C186 microprocessor.

The signals received by the HESTIA DU detector are shown in Fig.9.

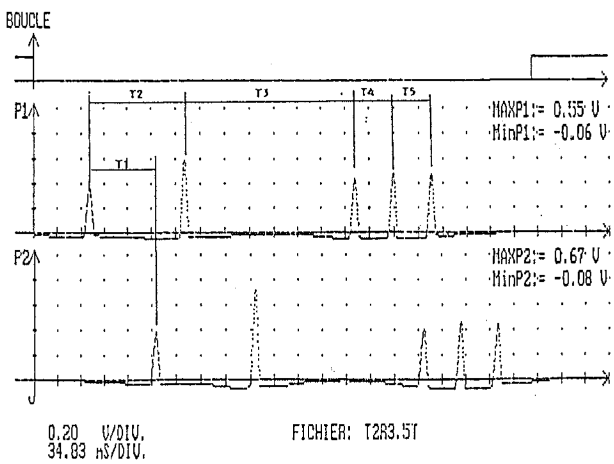

FIGURE 9

The system works by sampling during the induction loop detector switching time.

The speed is calculated from time T1 and the distance between the sensors.

The distances between the axles are calculated from the times T2, T3... and from the speeds of the vehicle. The category is worked out from distances and weights.

SIGNAL PROCESSING FOR WEIGHT CALCULATION

Signal processing is carried out on each of the two piezo electric sensors independantly. It is therefore possible to compare the results obtained from each of the two sensors, providing that the speed has been correctly measured. If it is not measurable, its value will be fixed by default at 100km/h.

Furthermore, in order to optimise the accuracy of the system, only the most accurate sensor will be taken into account.

In all cases, it can be seen that the use of two sensors improves measurement, either by averaging the measurement of the two sensors or selecting the most accurate sensor.

Signal processing is carried out in relation to the surface impulsion measurement produced during the passage of an axle.

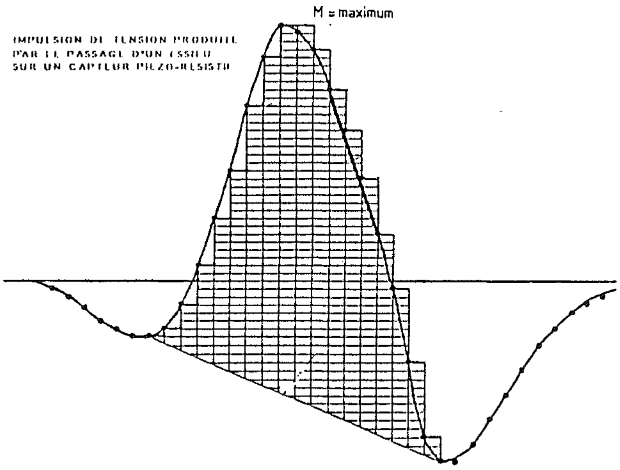

FIGURE 10

GAIN CONTROL ALGORITHM

It is necessary to optimise the analogue to digital conversion which takes place during signal processing by correctly amplifying the signals from the two piezo electric sensors.

To do this, the calculated amplification must be such that the impulsion produced by a very heavy axle (about 20 tons) is sampled on the maximum conversion scale.

AUTOMATIC CALIBRATION ALGORITHM

The automatic calibration algorithm carries out the calculation of the value to be allocated to determine the integral of the impulsions coming from each of the axles of the vehicles crossing the sensors. It is this value which allows calculation of axle weight from the signal surface.

The method used originates from a statistical study according to which the weight of the first axles of some vehicles (termed characteristic) whose total weight is above thirty tons, is on average equal to 6.1 tons. It has also been determined from this method that the total weight of these vehicles must be taken to be equal to 40 tons.

It should be noted that the different surfaces which have been used for the calculation have been previously corrected in relation to the speed of the vehicle and in relation to the amplification calculated by the gain control algorithm.

PARAMETERING

Detector parametering is carried out from the RS232 serial linkwith the help of a PC/AT compatible micro computer, either from command words or from the user definable ECoM software.

- the distance between sensors
- the choice of calibration method
  * pre-weighed vehicle
  * characteristic vehicle followed by the definition of type/s of vehicles, their characteristics, and the permanent calibration parameters (number of vehicles, weighting...)
- the retained classification
  * "European table"
  * ECM table
  * definable parameter classification followed by the definition of each class and sub-class.
- the definition of the sensor/s used for weighing.
- the secondary choices such as the lenght of the vehicle, presence time on the loop, lenght of the loop, inter-vehicular-time in seconds or milliseconds.

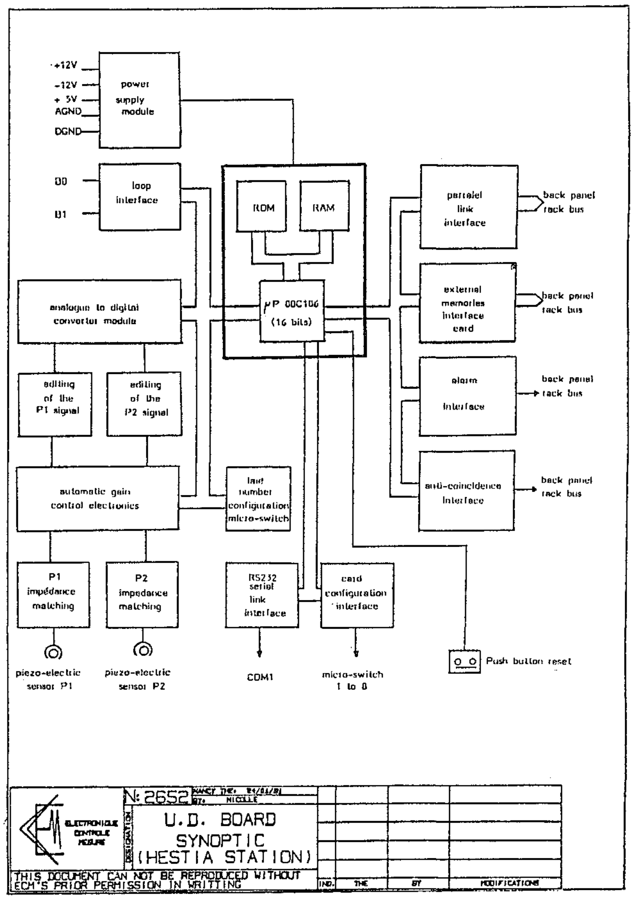

FIGURE 11

Elément Par mesuré	UNITE	détec.DU WIM	AVC	unité centrale	repère tableau 2
date	J-M-A	O	O	X	1
Heure (Mn/S)	H-Mn-S	O	O	X	2
choix capteur de pesée	I/O	X	O	O	3
N° de voie	0à7	X	X	O	5
caractère de validation	décimal	X	X	O	6
catégorie	00à99	X	X	O	7
vitesse	km/H	X	X	O	8
temps inter-véhiculaire	mS ou S	X	X	O	9
temps présence sur boucle	mS	X	X	O	10
nombre d'essieux	décimal ≤ 20	X	X	O	11
poids total	0,1 t	X	O	O	12
poid de chaque essieu	0,1 t	X	O	O	13 à 19
distance inter-essieux	cm	X	X	O	20 à 25

TABLE 1

MEASUREMENTS OF EACH VEHICLE

The data calculated for each vehicle is described in tables 1 and 2 according to the HESTIA DU detector type i.e. AVC or WIM. The central unit times the events.

(1)			(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
JOU	MOI	ANN	HRE	MIN	SEC	PZ	EMI	NUM	VAL	CAT	VITES	VHPRC/ms	PRES	NDE	PSTOT	PS1	PS2	PS3	PS4	PS5	PS6	PS7
!																						
22	04	91	16	44	14	11	077C	03	00	01	0144	00000932	0145	02	0003	0002	0001					
																0252						
!																						
22	04	91	16	44	17	11	077C	01	00	01	0096	00008217	0230	02	0010	0006	0003					
																0247						
!																						
22	04	91	16	44	20	11	077C	03	00	01	0122	00005905	0108	02	0010	0006	0004					
																0277						
!																						
22	04	91	16	44	21	11	077C	03	00	01	0126	00000709	0174	02	0006	0004	0002					
																0247						
!																						
22	04	91	16	44	26	11	077C	03	00	02	0098	00004517	0207	03	0026	0008	0011	0007				
																0240	0218					
!																						
22	04	91	16	44	26	11	077C	01	00	10	0005	00000000	0709	05	0350	0062	0123	0069	0062	0042		
																0329 (20)	0565	0135	0134			
!																						
22	04	91	16	44	28	11	077C	03	00	01	0114	00001935	0109	02	0004	0003	0001					
																0250						

TABLE 2

THE CENTRAL UNIT

The structure of the central unit is similar to that of the DU detector.

It uses the same 4 layer digital card, the analogue part having been replaced by a digital part including a "real time" clock and three RS 232 links.

The principal functions of the HESTIA CU card are as follows:

- dialogue with the HESTIA DUs
- memory management
- alarm management
- dialogue with the outside world
- visual display of the traffic in "real time"
- traffic data gathering in 4 different user definable forms
  - . vehicle by vehicle by integrating the traffic lane choice and vehicle types.
  - . SATL compatible statistics
  - . extended LOTUS 1.2.3. usable statistics, allowing users to create their own operating software.
  - . real tims which allows the integration of the station into a traffic management network. The stored data is only related to classified flows, occupation rates, average speed per lane and per six minutes periods.

MEASUREMENT QUALITY

The trials carried out on different sites have demonstrated that:

- speed accuracy is in the order of 2% for 90% of vehicles without any particular correction and remaining independant of weather conditions.
- profile classification is close to 100% due to good speed measurement.
- weighing on high quality road surfaces (HOLLAND) on 4 successive sensors show maximum divergence.

e = (maximum weight-minimum weight) average of 2 weights
of 10 % for 60 % of vehicles
of 20 % for 90 % of vehicles
- the divergence between the average measured dynamic weight of 19 vehicles and the average measured static weight is less than 2%.

This trial was carried out on a new pliable roadway (deflection around 80 hundredths of a millimetre) using resins adapted to the roadway. These results were obtained on two different lanes with the passage time of two different vehicles split between 9H in the morning with a temperature in the order of 16°C and the afternoon with a temperature of 29°C.

The maximum divergence between static and dynamic weight was 11%.

CONCLUSION

The development of a complex electronic measurement system requires an in-depth understanding of the sensor and the conditions in which it has to operate.

This sort of axiom led us to early sensor development and installation techniques.

The HESTIA station, the product of more than 150 man months of study, uses original concepts in its organisation as well as in the way the signal are processed.

Total automation of setting up and calibration tasks has been achieved. Measurement quality makes it perfectly usable for detailed statistical calculations.

New applications in the IVHS domaines are envisaged and are the object of new trials.

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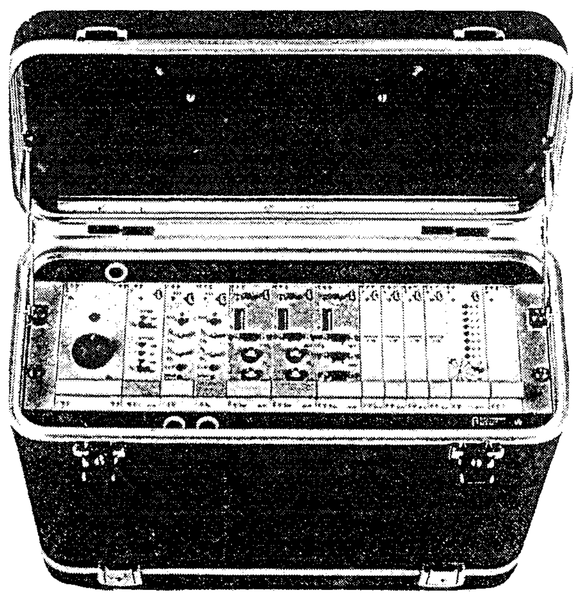

FIGURE 12
2 Lanes portable HESTIA