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

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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 ceramic 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 be taken into consideration in all application. We remind you simply of the following principals.
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.

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 whether the passage of the vehicle is rectilinear or not (figure 2).

If a ceramic or PVDF 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:

\[ V = k \Delta p - \frac{1}{t/r} \]

where \( r \) is determined by the system:

\[ \frac{1}{t} = \frac{1}{L} \left( \frac{1}{C} + \frac{1}{C_m} \right) \]

\( C_m \) and \( X_m \) respectively represent the capacity and the conductance of the measuring circuit.
\( k \) 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:
\[ 1 \]
2/ \( \Delta P \) 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 or 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 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).

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 installed jointly in traffic lanes carrying out dynamic weighing, and secondly on its own.

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)

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 material type element. The lifespan is essentially due to fast fitting techniques.

3. SECOND GENERATION 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
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](image_url)

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

- from lanes A and B piezoelectric 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.

The central unit (5) will allow dialogue with:

- 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 Megabyte protected by lithium cells.
- the "ALARM" card (8)

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 converters (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 maximum 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](image_url)

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.

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SIGNAL PROCESSING FOR WEIGHT CALCULATION

Signal processing is carried out on each of the two piezoelectric sensors independently. 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 optimize 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.

GAIN CONTROL ALGORITHM

It is necessary to optimize the analogue to digital conversion which takes place during signal processing by correctly amplifying the signals from the two piezoelectric 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 link with 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-weighted 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"
  * ECOM 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 length of the vehicle, presence time on the loop, length of the loop, inter-vehicular-time in seconds or milliseconds.
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.

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", allowing users to create their own operating software.

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.
HEAVY VEHICLES AND ROADS

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
envisioned and are the object of new trials.

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FIGURE 12
2 Lanes portable HESTIA