DEVELOPMENT OF A SYSTEM FOR MONITORING OF THERMO-ACOUSTIC INSTABILITIES IN LIQUID PREMIXED BURNER FOR GAS TURBINES

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R.Bruschi (*); C.Stringola (*); S.Giammartini (*); F.DiCarlo (*); V.Casasanta(*)
F.Pittaluga (++); M. Caruggi (++)

(*) ENEA – C.R.Casaccia, Rome
(++) DIMSET University of Genova

Introduction

With reference to the development of an innovative breed of liquid fuel gas turbine burners, based on the dry premixing combustion and characterized by low emissions in terms of Nox and CO, a great interest is focused on the prevention and the monitoring of the thermo-acoustic instabilities (humming), induced by the air-excess variation in operative transitory.
This report describes an in-progress activity, oriented to the development and the application of a monitoring system, just developed for gas fuels, focused on the analysis of the *humming* incipient conditions for liquid fuels in premixed combustion.
The system is based on a monitoring of acoustic/visual kind and it has been validated by means of chemical analyses in the flue gas, by means of IR and mass spectrometers.
The experimental activity has been carried out in ENEA laboratories of Casaccia-Rome (ENEA-ENE/IMP) and Savona Combustion Laboratory (DIMSET/SCL).
The monitoring system permits the observation of the specific phenomenology, by means of the synchronous acquisition of the process variables, the emission values, the pressure signals and the digital images at high acquisition frequency (10 kHz for the pressure signals, 800 fps for the images).
Data processing permits to characterize the thermo-acoustic fluctuations due to the incomplete mixing of liquid fuel in air.

1. The humming problem.

In turbine burner systems to maintain low NOx emissions it is necessary to limit the flame temperature, but to obtain the maximum turbine efficiency its input temperature should be as high as possible. The use of premix burner is a valid compromise. In combustion chamber of those burners, especially when low air excess factor is used (minus of 2 stoichiometric value), a positive feedback is possible between the heat release rate of the flame and the pressure wave due to acoustic features of the same chamber system. This phenomenon, usually named “humming”, causes the dangerous thermal and mechanical overloads to the system structures, thus it is very important to avoid it. The authors of this report believe that a correct approach to problem solution is essentially to dispose of systems for a better legibility of the humming phenomenology: this system is the object of work reported. The basic concept of this system is, how better described after, to find and observe how a variable that is intrinsic to the combustion process is correlated to acoustic pressure wave.

2. The monitor system.

The humming monitor system is based on the concept that the brightness fluctuation of the light emitted by the combustion is strongly correlated to pressure wave; the delta variation (time derivative) of the integral of the image brightness was used like the combustion intrinsic variable. So we used a digital video-camera like brightness sensor and piezoelectric wide band sensor for pressure wave. Another concept used was: if the feedback loop between the two variables are the resonance band frequency channels then also the variations of relative band energy signal should be correlated (this solution permitted to use references, like resonance band range, not too much defined). The main rule for a right functioning was the hardware synchronisation of the sub-systems. The system was implemented on a PC platform and developed in Labview software environment.

Three sub-systems were realised:

- management: to set all measure parameters and preset the other sub-system to start acquisition.
- process acquisition: to acquire pressure sensor and generate the external clock for image system (pressure sensor: Kistler 6061B, 0-50 bar,-50-350 °C, charge amplifier 5011B).
- Image acquisition: to acquire, via dma, the flame images following the external trigger (digital camera: DALSA CA-D1, 127X128, 850 fps).

All data were logged in data-files.

Setting parameters:

- process acquisition:
    sample freq. 10KHz
    charge amplifier for sensor pressure: low pas cut freq. 3KHz
    trigger for camera hardware triggering (800Hz)

- digital camera: external triggered

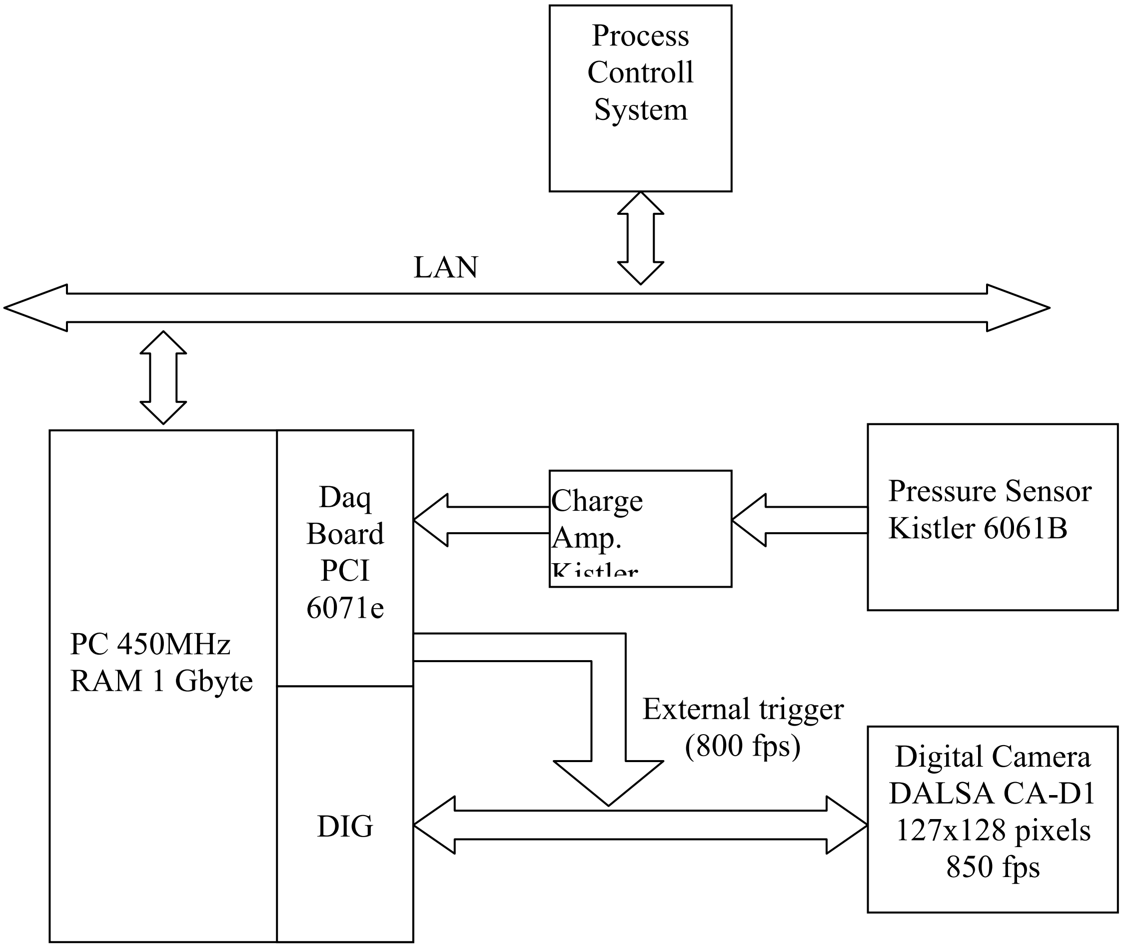

Fig. 1 Layout of Humming Monitor System

3. Plant description.

Technical setup.

The test of the monitor system was done on a facility of Savona Combustion Laboratory (DIMSET/SCL).

Fig. 2 Lateral/retro view of the LRPM and particular about camera and pressure sensor positions.

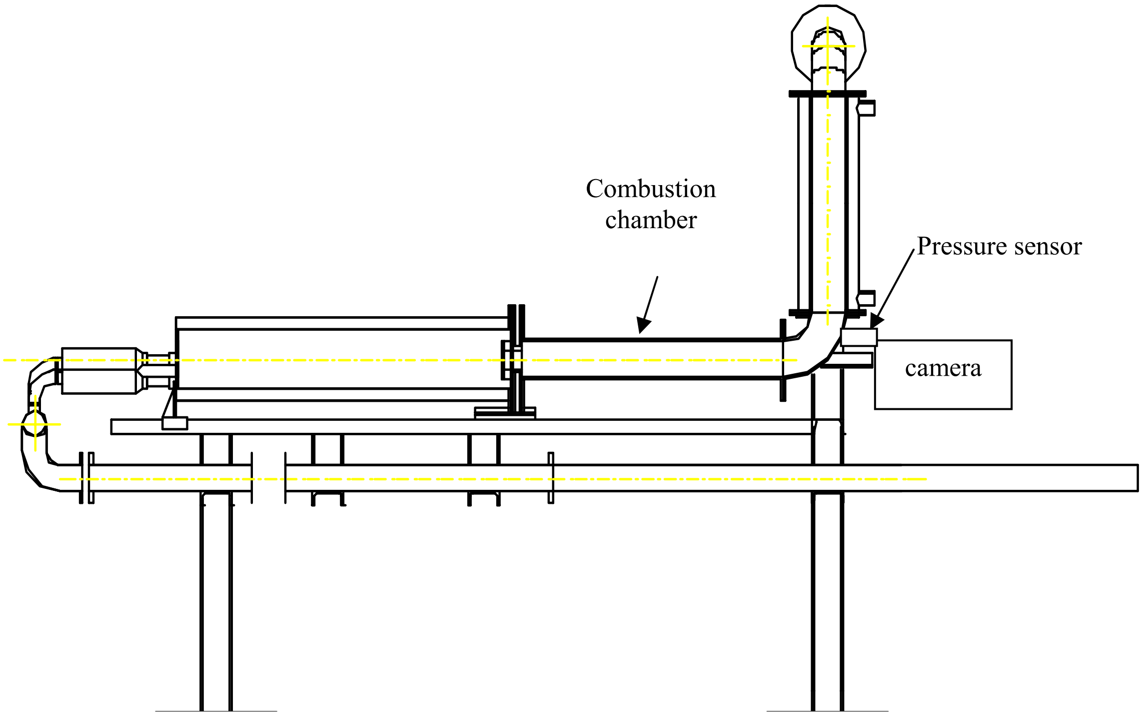

Fig. 3 LRPM structure diagram and test points.

Components and features of the **L**iquid **R**apid **P**re **M**ixer are :

- Air compressor (500 kg/h max)
- Air heater (108 Kw, max 800°C).
- Mixer (1500mm)
- Combustion chamber (300mm)
- Chimney (1200mm)

The burner mounts a particular swirler that impose a strong tangetiality to the mix for that it haven't need of the pilot flame.

4. Data analysis and results.

To do the test was increased the fuel-flow to obtain a reduction of air excess factor (this to maintain constant the air-flow that is more difficult to measure and so it was better to leave that in its steady state). In normal condition an air excess factor 2.86 (air-flow 288 nmc/h, fuel-flow 0 .168 l/min) is used, to obtain the instability condition this one is modified to 1.7 (air-flow 288 nmc/h, fuel-flow 0.232l/min)

In the following figures it will be possible to understand how the monitor system works and what is able to detect.

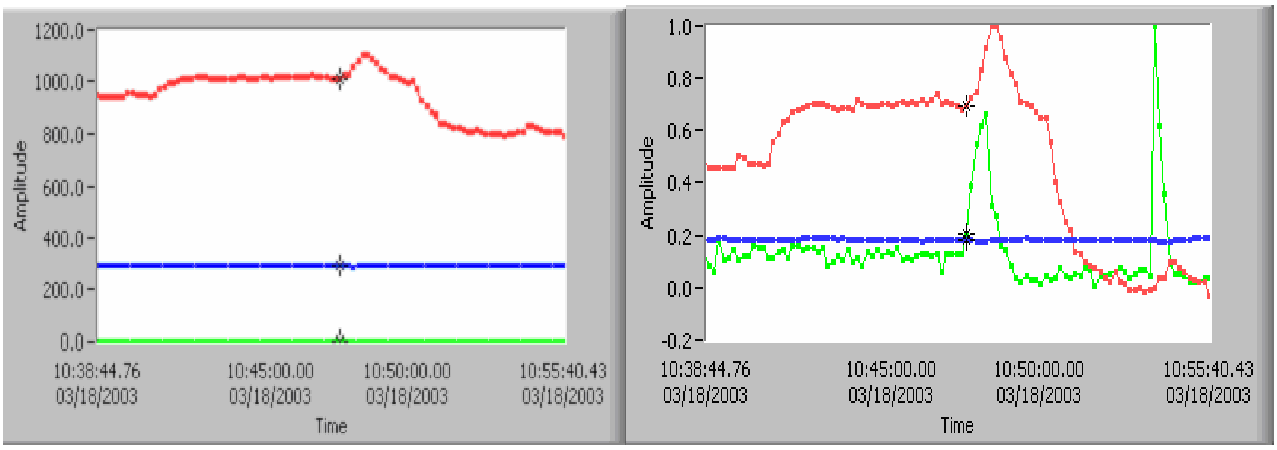

Fig. 4 Trends of process variables recorded on pc control process. Values before humming instability. Real and normalised display.

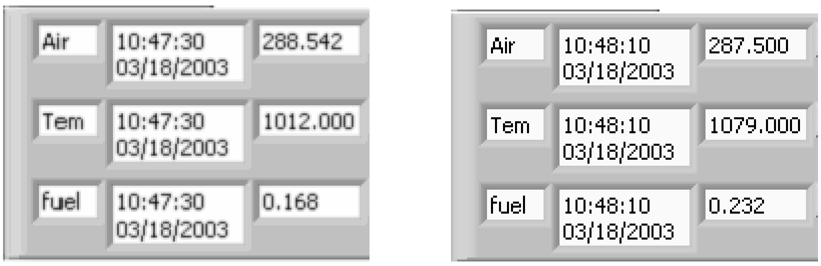

Fig. 5 Values of Air-flow, Combustion Chamber Temperature and Fuel-flow before and during the humming instability

In figures 4 and 5 it is possible see how the test conditions were obtained. It's possible to note that change of fuel-flow from 0.168 to 0.232 g/s while the air flow remain steady at 288g/s, so it was obtained a great reduction of the air excess factor.

At this conditions the humming phenomenon start and remain up to return normal air excess factor.

In the all figures it is possible to control the time coherence. In the figure 6 we can note how much is strong the coherence between humming and brightness.

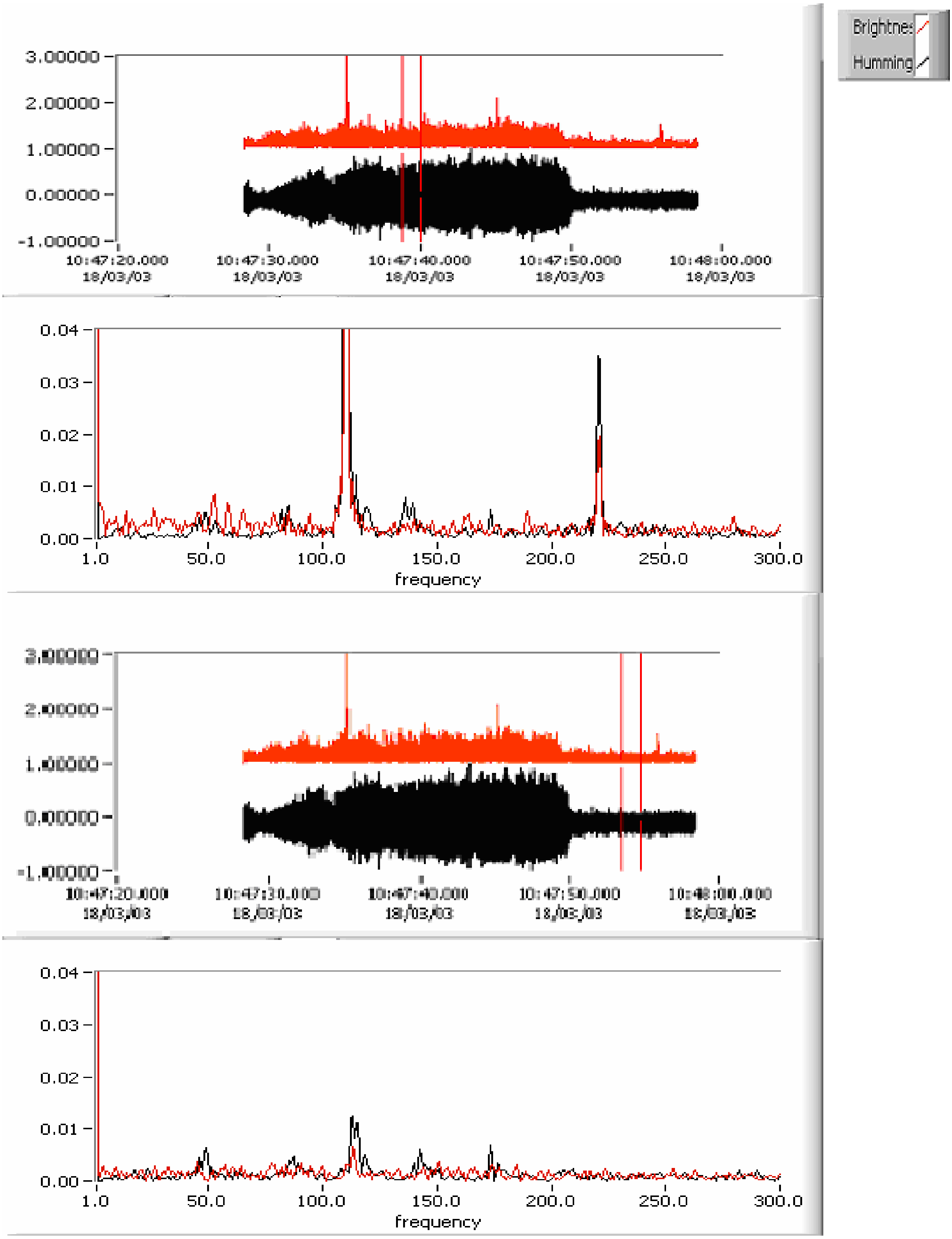

Fig. 6 The diagrams show the time and the frequency domain during and after humming instability. The black is the humming variable and the red is the brightness variable.

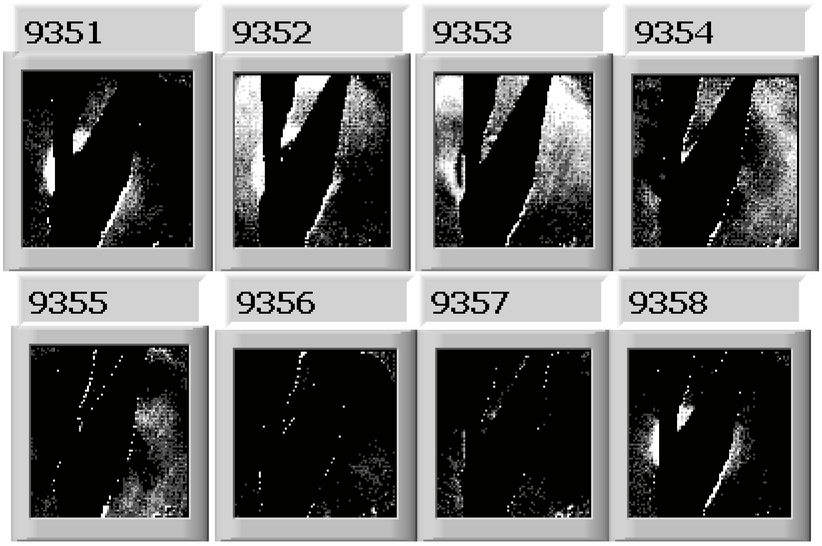

Fig 7 Frame sequence while the system is in humming

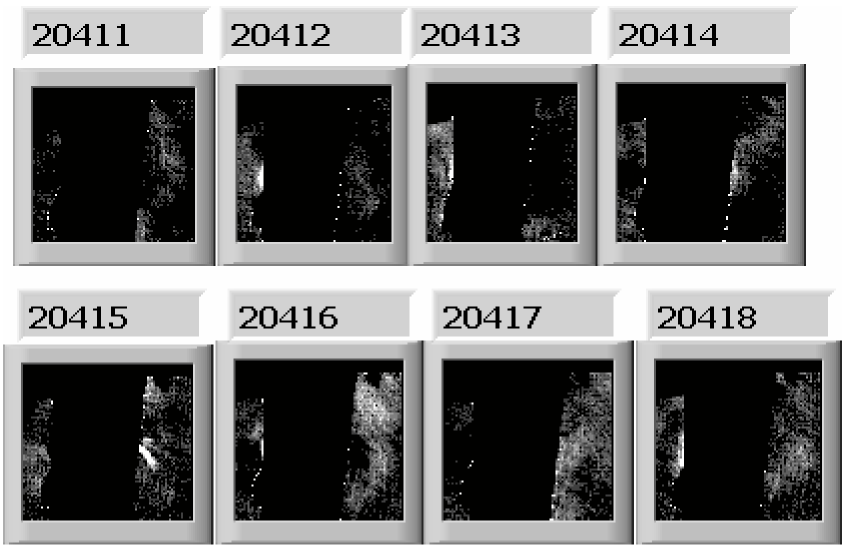

Fig 8 Frame sequence while the system is out humming

From figures 7 and 8 we can observe how the brightness changes during the humming. The object which we can see in front is a bulk of the thermocouple used to measure the temperature inside combustion chamber. Knowing the frame frequency of 800Hz, and counting the period at 7 frames (fig 7) we have the brightness frequency equal to 114 Hz. From figure 8 we can note that the brightness change is low in fact them were acquired in normal codition (without humming) .

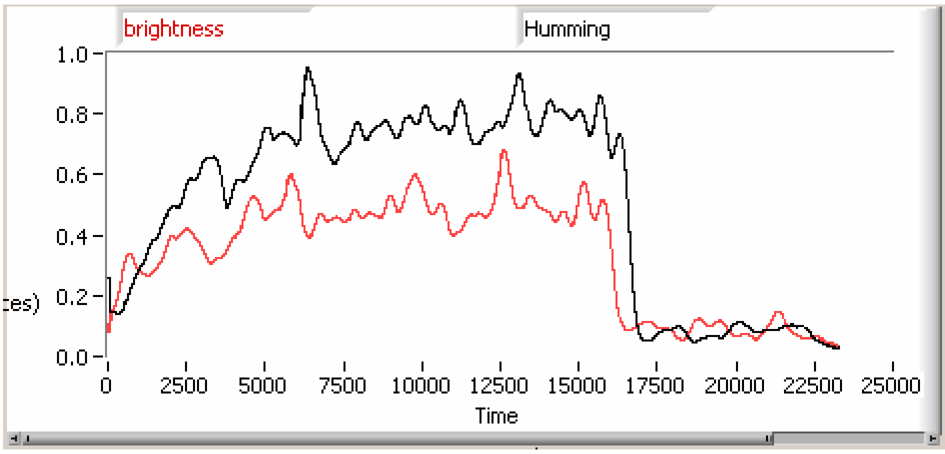

Fig 9 In this diagram is show the time coherence between humming and brightness.

The figure 9 is obtained doing the envelope in the time of the signal energy contained in resonance band. It is notable how inside the humming there is a strong correlation between brightness and pressure variations and outside humming this correlation is little; and more, on left side the diagram, during incipient abnormal conditions, we can see how the brightness trend is different from that one of the pressure sensor: the trend of brightness variations it is not linear and shows probable pre-humming events.

5. Conclusion

The system realised is able to detect the instability (humming conditions) using the brightness sensor only, this method appears effective, sure and robust and more is low cost, respect to sensor pressure. The good results make this system likely to improve. Now we trying to exploit how much this method is able to be an early detection about the flame instabilities.