ACOUSTIC EMISSION TO ASSES THE STRUCTURAL CONDITION OF BRONZE STATUES. CASE OF THE “NIKE” OF BRESCIA

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Abstract

Structural stability of bronze statues is an important problem. These bore, in fact, as works of art more than as engineering projects. Therefore poor attention is paid to own structural conditions, so failures can occur, which can even be a danger for the survival itself of the statue.

Bronze ones, in fact, may be subjected to corrosion, cracking and plastic deformations phenomenon, due to incautious conservation and transport, and to environmental thermo-hygrometric cycles.

The paper presents an Acoustic Emission (AE) method to solve the diagnostic problems which can arise about the conservation state of the famous statue of the “Nike” in Brescia, named “Vittoria Alata”.

The statue was in bad structural conditions, caused in the past by several operations aimed to the statue conservation and the aesthetic modification.

The AE technique, with strain gauges testing, allowed to asses the conditions of optimal trim and to characterize structural alterations.

Introduction

The use of the Acoustic Emission for the structural characterization of the bronze statues, though not of recent application [1], is still a few frequent in spite of the meaningful results until now reached.

The defectiveness on the bronze statues can originate during the casting and the assembling of the several elements, separately casted. Further defectiveness can be induced by mechanical and chemical stress on behalf of the environment. Such stress can came from hit, fallen and not correct handlings of the statue.

All this events can produce in the bronze defectiveness like porosity, plastic deformations, cold welding, corrosion, and cracking that can evolve with specific environmental conditions, and collapse the statue. In this case the statue is loss.

Therefore for a correct conservation of the statue is important to asses the influence and the critical situation of the defects versus the exposition conditions.

The Acoustic Emission method is very effective for this application because it is able to identify, under stress conditions, the active defect type and its structural criticality. In such way it is possible to characterize the defect evolution in the statue.

The Acoustic Emission, inasmuch as it is absolutely passive and not invading NDT methodology, is particularly right for operating on cultural heritage, because works of art are, in comparison with the industrial manufactured articles, unique and unrepeatable.

The introduced case in this memory concerns the evaluation, for conservative purpose, of the criticality of the structural state of a particular bronze statue of Roman Age, representative the Nike, the goddess of the Victory. The statue is become symbol of Brescia from the 1826, when it was recoverd in occasion of an archaeological excavation in the Roman *Capitolium*.

The bronze statue of "Nike di Brescia"

The statue, about two meters tall (Fig. 1), has been casted in Roman Age (III century b.c.) in a classical alloy (Cu-Sn-Pb), and it is now preserved in the museum of Santa Giulia in Brescia. The statue has been find, in the excavation of the 1826, with no arms and no wings, that were, disassembled, next to the body.

Fig. 1

To assemble it again, in the 1826 was designed a special iron support that was inserted inside the statue, to hold up the wings and the arms, by means of connection pivots,. The support crosses all the statue along its axis, from head to pedestal. In Fig. 2 you can glimpse the inner support of the statue and the left wing connection pivot, through the hole left free from the dismantlment of the left arm. The connection pivots are inserted in the body across special holes, made in the higher part of the back in the past.

This structure has determined, from the beginning, locally anomalous stress on some zones of the statue. Such stresses may have contributed to make particularly critical the moving of the statue in the museum, (i.e. for restoration or to protect it from the war events by the 1826 to today.

According to a historical-artistic reconstruction of the statue it has come to the conclusion that it originally represented the Aphrodite goddess and, in following age, it was transformed in the Nike goddess by insertion in the back of the two wings,.

Therefore since such transformation was not originally provided from the sculptor, it has weakened the statue structure on account of the displacement of the axis and the barycentre. In such way stresses bending, originally not provided, were established on the back.

Fig. 2

In conclusion at present the statue shows the evidence of plastic deformation and cracking of such extension to arouse strong worries for its structural stability.
Therefore the diagnostic problem was to characterize the criticality of such defectiveness, to individualize the growing condition and parameters. Furthermore it was important to asses if the wings presence and the inside support were cause of defects growth. The conditions to consider are inherent the normal position in the museum for the public exposition and the handlings for exceptional events (exibitions, restoring).

Experimental procedure

The definite parameters to characterize the conditions of exposition in the museum were, in addition to the thermal-hygrometric environmental parameters, the mechanical stress induced from the static stress for the presence or less of the wings.
Besides this situation it has been considered even the eventuality of an handling of the statue. In such case the considered mechanical parameters were ones dynamic for the stress inherent standing position modification of the statue, during the handling.
To get information about the deformations under load of the structural parts of the statue, in addition to the investigation with Acoustic Emission, strain gauge measurements were done. In such way acoustic emission signals were more easily attributed to the event of plastic deformation under stress and to the evolution of micro cracks.
Therefore the diagnostic investigations with Acoustic Emission has been done:

a) In the normal static standing position of the statue in the museum;
b) In dynamic condition during the moving of the statue from a room of the museum to the other, with relative its lifting and its putting again on the pedestal.

*L*ocation of the transducers

Acoustic emission and strain gauge transducers distribution and location on the statue has been made on the base of the cracks position in the believed critical zones, from a static point of view, by means of visual inspection.
As well it was kept observations and considerations about the distribution of the stress on the connection pivot of the wings to the intern support, trough the holes on the back.
A difficulty for the positioning of the acoustic emission and strain gauge transducers cams from the irregularity of the bronze surface. Indeed the statue is covered with a large and rich drapery that doesn't allow an acceptable coupling of the sensors on the bronze. Only in the *naked* zones of the body it was possible to find enough smooth surfaces to allow a correct coupling. In addition the surface of bronze was covered from a corrosion product patina that must be kept and preserved. To such purpose a high molecular weight grease was used and it was kept separated from the patina by a PARALOID B/72 thin film.
To well appraise the shading and the propagation speed of the acoustic emission signals in the various parts of the statue, calibration measures were preventively done (Fig. 3).

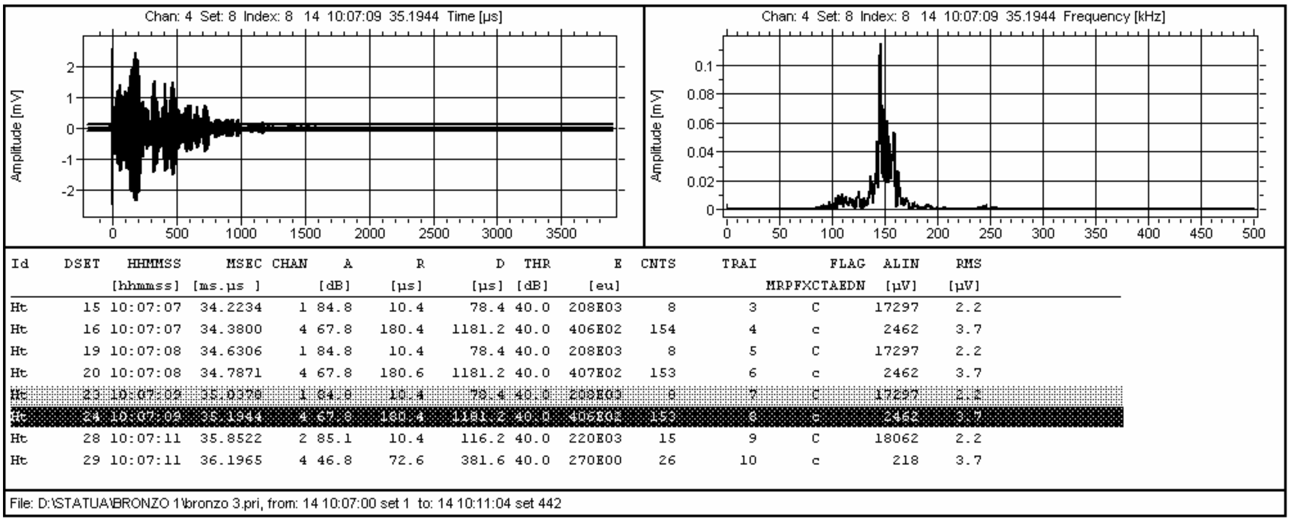


Fig. 3

Therefore in the higher part of the statue in proximity of the more damaged zones three sensors were positioned: one on the back side of the neck, one on the breast, and one other near the navel. Since it had been pointed out a difficult ultrasonic continuity of all the statue, composed by several components assembled by restrained joint or by not continuous welding, a sensor was positioned on the left foot, to get information on the behaviour of the lower part of the statue and of the support-plinth system.

Acoustic emission equipment

A six-channel AMSY type-5 SYSTEME VALLEN Gmbh acoustic emission instrumentation was used. The sensors were of 150 kHz resonant type, and the preamplifiers had gain of 34 dB and a high pass filtering.
To evaluate experimental data the VALLEN VISUAL AE and VISUAL TR software programs was used.

Results

a) Static standing conditions.

The investigations have been done on the statue in its complete configuration and then compared with taken away wings and arms configuration.

During the 10 days monitoring signals due to plastic micro-deformation and to cracks growing were obtained, above all in the immediately following period after the wings assemblage, that is during the settling of the structure in the new conditions.

In the Fig. 4 an evident signal of crack appears in the 4° monitoring day. The strain gauge measures let confirm such defectiveness; in the following period the growing of the cracks, above all in the higher part of the back and near to the neck, becomes less intense, remaining however present.

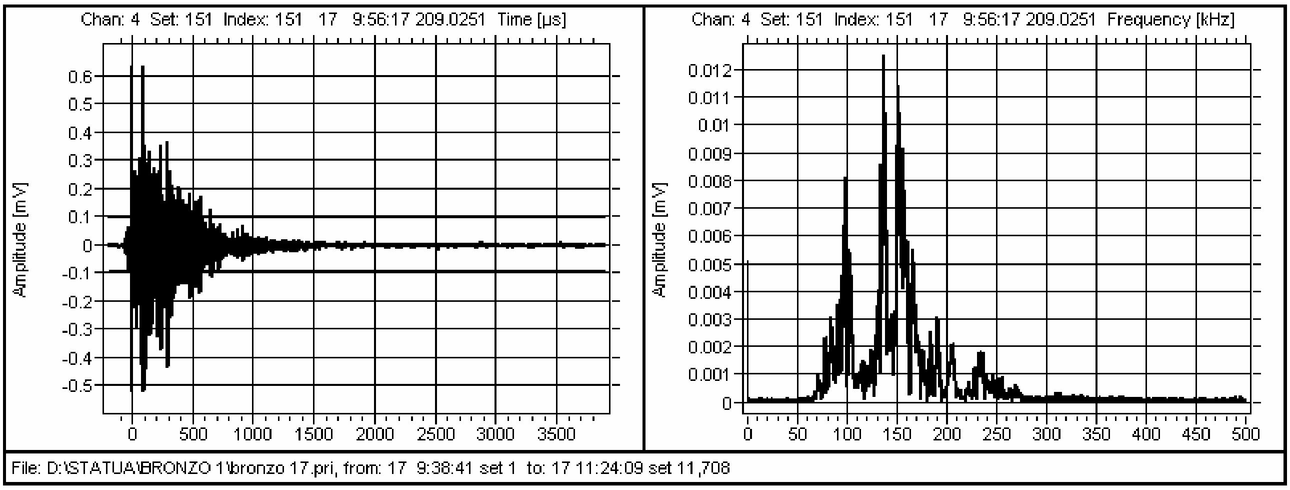


Fig. 4

b) Dynamic standing conditions.

During the moving of the statue and its new positioning on the pedestal, the axes variation of the statue produced an intense acoustic activity due to the evolution of the present defectiveness above all in the zone of the back and near the neck.

The figures 5 and 6 show the diagram of the Acoustic Emission of the sensor close to a present defectiveness on the back and the diagram of the relative strain gauge measures on the same zone, during the same time period. It may observe periods of intense emission in correspondence of the inclination variation of the statue during the transport and in the latest part of the graph the strong emission during the new positioning on the pedestal.

The strain gauge monitored zone, to which is reported the diagram, is that relative to the proximity of a showy present crack on the back. It is manifest the agreement of the reached results by the two investigation techniques. That has allowed to get a better evaluation of the criticality of the stress to which the structure can be submitted and a better discrimination of the type of defectiveness in advancement phase.

In the same monitored period, in the zone of the neck as well, many cracks signals were collected, as reported in the example of Fig. 7.

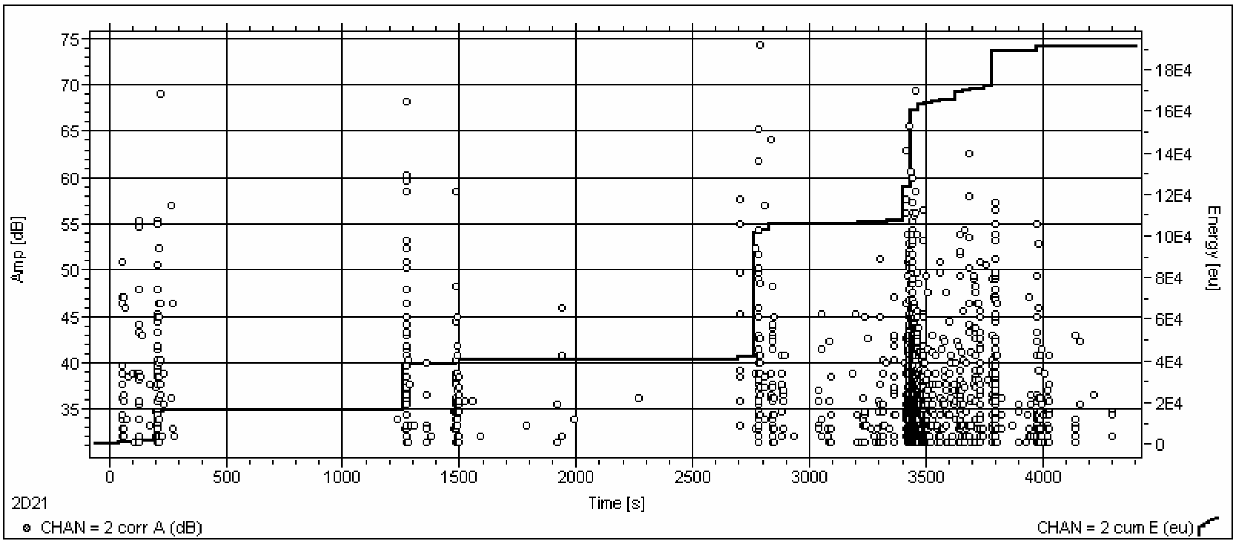

75
70
65
60
55
50
45
40
35
Amp [dB]
0
500
1000
1500
2000
2500
3000
3500
4000
Time [s]
18E4
16E4
14E4
12E4
10E4
8E4
6E4
4E4
2E4
0
Energy [eu]
2D21
CHAN = 2 corr A (dB)
CHAN = 2 cum E (eu)

Fig.5

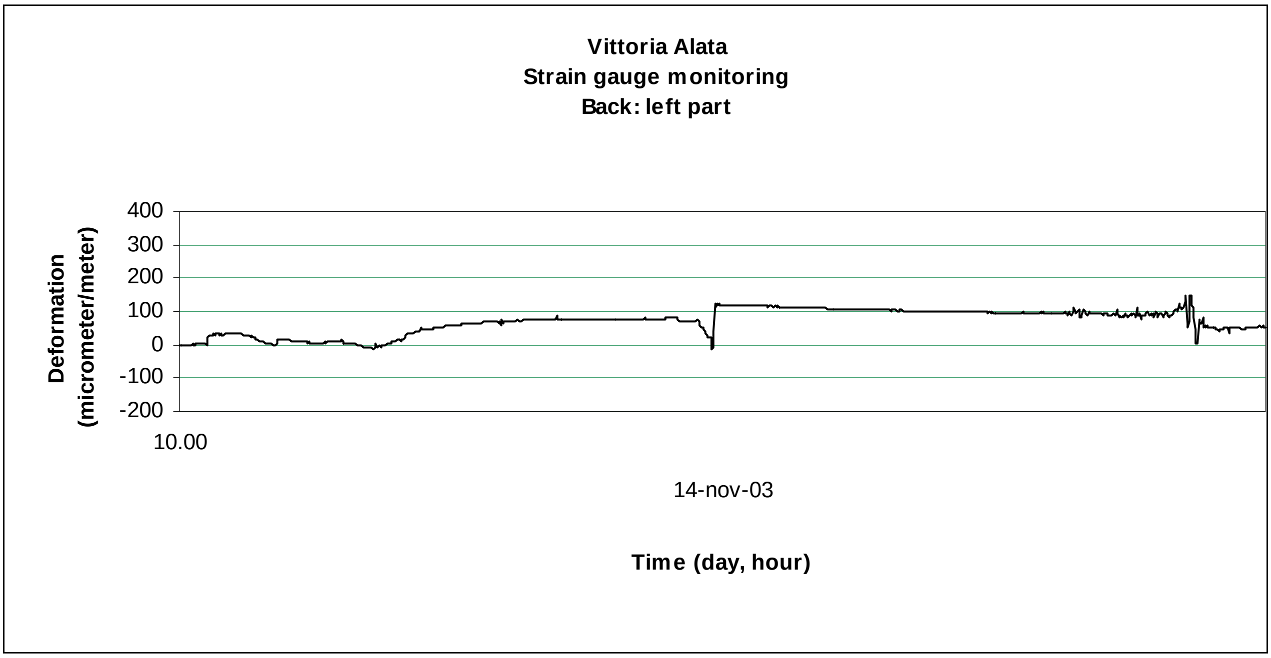
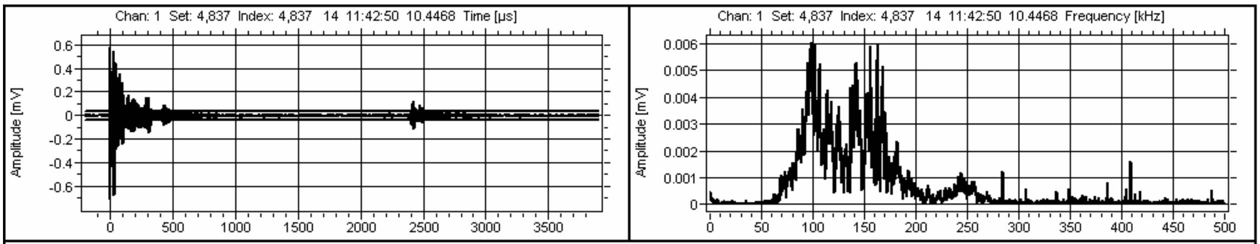

Vittoria Alata
Strain gauge monitoring
Back: left part
400
300
200
100
0
-100
-200
Deformation (micrometer/meter)
10.00
14-nov-03
Time (day, hour)

Fig.6



Id	DSET	HHMMSS [hhmmss]	MSEC [ms.µs]	CHAN	A [dB]	R [µs]	D [µs]	THR [dB]	E [eu]	CNTS	TRAI	ALIN [µV]	RMS [µV]
Ht	15016	11:42:49	948.6683	4	38.1	85.6	583.2	30.6	468E-1	36	4833	80	4.0
Ht	15017	11:42:49	949.0689	1	31.3	0.2	76.6	30.6	609E-2	1	4834	37	5.5
Ht	15019	11:42:49	959.0455	1	32.1	0.2	295.2	30.6	784E-2	1	4835	40	5.3
Ht	15020	11:42:49	959.4111	4	31.3	0.2	0.6	30.6	435E-2	1	4836	37	4.0
Ht	15022	11:42:50	10.4468	1	57.7	33.8	564.6	30.6	652E00	56	4837	764	5.1
Ht	15024	11:42:50	99.6423	4	34.8	468.8	720.4	30.6	246E-1	14	4838	55	4.0
Ht	15026	11:42:50	102.5330	4	32.8	0.4	52.2	30.6	792E-2	2		44	4.0
Ht	15033	11:42:50	154.7692	4	34.8	11.6	277.6	30.6	152E-1	11	4839	55	3.4

File: D:\STATUA\BRONZO 1\bronzo 5.pri, from: 14 10:35:49 set 1 to: 14 11:48:15 set 15,880

Fig. 7

Conclusions

Acoustic emission monitoring allowed to get an exhaustive diagnostic evaluation of the structural state of the Nike of Brescia in the different situations that are presented.
Two possible situations have been considered: a) situation of static standing that characterizes the statue in its stable and definitive position in the dedicated room of the museum, and b) situation of a varying standing in the moving case of the statue from a place to an other.
In the first case it was observed that, from a stress point of view, there are substantially not differences between the statue with only the arms (with no wings) and the statue with no arms and no wings. It means that the presence of the arms das not alter the static equilibrium. Instead the presence of the cantilever wings on the back makes a lever arm. This situation moves the position of the barycentre establishing a state of stress.
The stress is located on the back, among the neck and the made holes for the insertion of the pivots hooking the wings to the inner support.
In the second case the handling of the statue induces particularly strong stress conditions. Conditions due to:

a) continuous variation of axes: because the statue is forced to varying inclinations on few support points, generating bending moments on several zones. In particular in the zone of the neck and of the upper part of the breast, the present defectiveness (macro and micro cracks) came forced to evolve.

b) vibrations, due to the transport.

c) anomalous stress due to the lifting of the statue for the positioning on its pedestal.

Then the handling involves situations of structural criticality that will evolve present defectiveness and will generate more ones, creating precariousness states on the whole statue and in its connection with the support.
The associate use of the strain gauge monitoring allowed to give a qualitative and quantitative evaluation of the induced defectiveness in the different situations.

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