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A NEW 3D TRANSDUCER FOR MEASURING THE TRUMPET MOUTHPIECE FORCE

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Brass player and teacher usually stress the importance of the applied mouthpiece force while playing the instrument. First publications by Barbenel et al (1986) and Petiot (2003) proved some myths wrong:
Wind musicians are not aware of the real magnitude of this pressure. Its range is between 5N and 40N depending on dynamic range and pitch. Today brass player are interested in real-time feedback.
In this paper a new transducer for measuring the static forces a player applies to his lips (characterizing his embouchure) is introduced. Three strain gauges register not only axial but also bending forces between mouthpiece and lead pipe. Due to the specific design of the device, the musician can use his own instrument and mouthpiece.
Measurement results are captured during a musical performance and simultaneously displayed with the real time waveform. The data acquisition software allows to record the applied forces along with the played sound to facilitate subsequent correlation analysis. The measuring device consists of three strain gauges which are placed radial in 120° distance around the axes of the mouthpiece. This gives insight into the 3-dimensional nature of bending and shear forces eventually created by musicians during playing.

Key words: music acoustics, transducer, trumpet, mouthpiece pressure sensor, pedagogies

1 INTRUDUCTION

Trumpet playing is muscle work. Evidently, there is the fine motor manipulation of the embouchure muscles (see **Fig.1**). Secondarily but also very important is the activity of the whole body of the player, including the arms to hold the instrument and the chest to provide the air supply. As shown in previous studies by the authors [1,2,3,4], there is a huge range of variations between players how they actually sound the trumpet. This study focus on the muscle activity of the arms, which hold the instruments against the lips.
This parameter, the mouthpiece force, has been studied 1986 by the bioengineer Joe Barbenel and the psychologists John Davies and Patrick Kenny [5,6,7] (reprinted by ITG [8]). They compared 22 players and proved many myths as wrong: There is no nonpressure embouchure because you have to close the gap between mouthpiece and the lips.

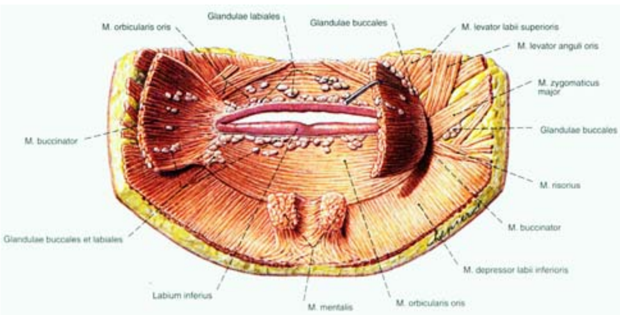

Fig. 1. Muscles performing the trumpeters hard work. As shown in previous studies, it is not the trumpeter muscle (Musculus buccinator) which acts as main muscle. *From Sobotta, J. Atlas der Anatomie des Menschen. München: Urban, 1993. S.91*

Barbenel et al. showed, there is a minimum effort and “even professional players of the highest calibre do not use low levels of force on the mouthpiece”. Further they found that one can not differentiate amateur players from professionals in terms of amount of force the use.

In general (mean values), the mouthpiece pressure increases from about 5 Newton in the low register (g3) to 10-20 N in the middle register and 20-40 N in the high register. (This equals up to 4 kg or 9 pound mass on the lips!) The amount varies by dynamic and player. At SMAC 2003 Petiot presented a similar study with a new design of a transducer [9]. They showed results for cornet players, similar as Barbenel.

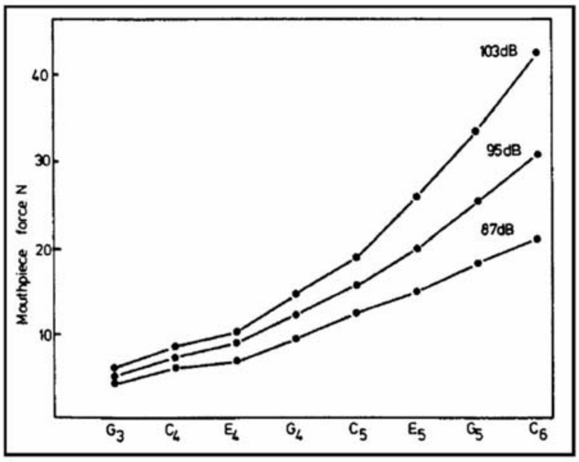

Fig. 2. Results of the Mouthpiece force measurements by Joe Barbenel, John Booth Davies and Patrick Kenny as published by ITG 1988

Of course, it is very interesting to see these data of other players. However, as our research institute is located at a music academy, where hundreds of players come across we have been motivated by students to continue the research on this parameter and to develop a prototype of a measuring transducer, that can be used as a real-time feedback teaching-aid like a tuner.
Further, the authors have experiences to play themselves their trumpets with very different amounts of lip pressure. For pedagogical reasons it could be a help to demonstrate that one player realizes similar notes with different amounts of pressure.
For example at the beginning of a long rehearsal, players try to avoid much “arm pressure” and “red faces”. At the end of a rehearsal or concert the embouchure is more fatigue and the playing technique often changes.
Additionally, mouthpiece force is not only directed centered. Target of this new type of transducer is, to measure the mouthpiece force in three dimensions. These values contain a lot of embouchure information and would allow to quantify playing parameters.
Since works by Daniel Martin 1942 [10], Dean Ayers 1995 [11] and many others (as summarized recently by Campbell [12] and Kausel [13]) we know more about the complicated 3-dimensional lip vibrations - but still many parameters are not defined. Experiments on lip vibrations done at our institute since 1995 gave also new insights of the actual playing technique (see **Fig. 3** and video samples online at www.bias.at/TRP). Though, the visualization also provoke new questions like “how much mouthpiece force players apply”.

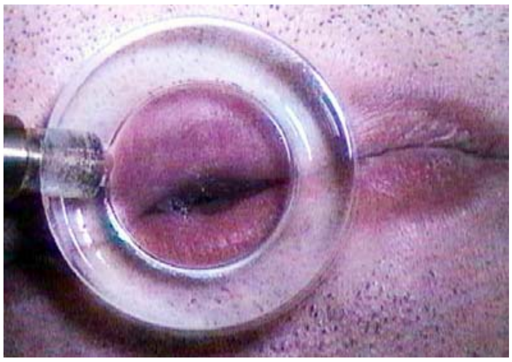

Fig. 3. The embouchure: mouthpiece rim area is hold against lips with different amounts of pressure

While it is new to see the variations between players inside the mouthpiece, it is obvious that there are a variations between players in the embouchure setup, the holding position and the amount of pressure.
The following pictures in **Fig. 4** show 21 trumpeters playing the same note with the same dynamic! One has not to be trumpet teacher, to see differences in the holding position. Even trumpet teachers do not know, how much effort players use, since e.g. a “red face” can be a sign or not.
Of course, there is no optimum pressure for all players and tools like this transducer can not teach how to play trumpet. However, feedback about the actual mouthpiece pressure and it directions can and will help players to find their individual best setup.

2 THE TRANSDUCER DESIGN

Demands on the measurement system:

- Easily attachable to a personal trumpet – mouthpiece combination
- With as little influence on the playing situation as possible
- Measurement of the force in three dimensions
- For direct reading
- Simultaneous sound recording

Because of the fact that the sensor element should fit to most common lead pipes and mouthpiece shafts, an industry-standard force transducer will not meet the requirements. Designing a custom transducer device solves this problem and provides the means for measuring “lip force” in all three spatial dimensions.

Fig. 4. Playing Position of 21 professional and student players for playing a c5 (middle register) [1]

2.1 The mechanical assembly

This paper describes the design of a special three dimensional force transducer, the 3D gauge, the data capturing software and first measurement results. The sensor device consists of four parts made of brass. **Fig. 5** gives an overview of the assembled device:

- Mouth piece receiver
- Strain element
- Counter piece
- Mouthpiece shaft

As shown in **Fig. 5**, the strain element has three 2mm thick brass wings labeled a, b, c. In order to get force information about all three directions (x, y, z) these wings are placed radial with angle increments of 120° around the mouthpiece axes.

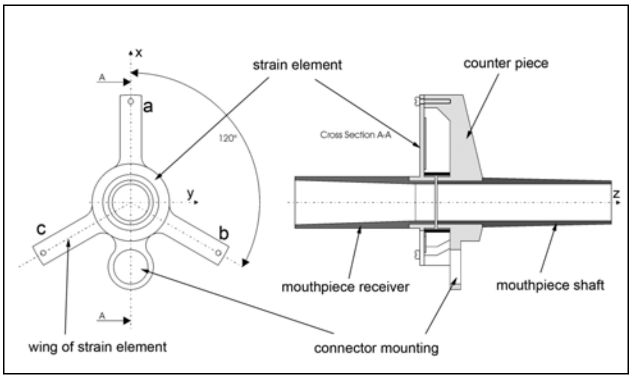

Fig. 5. Cross section of the assembled transducer

The wings become stressed, while a mechanical force engages between the mouthpiece receiver and the mouthpiece shaft. Strain gauges attached on these wings will then change their electrical resistance according to the effected stress. As long as the magnitude of the stress stays in the linear and elastic range of the strain element material, resulting resistance variation will be proportional to the applied force.

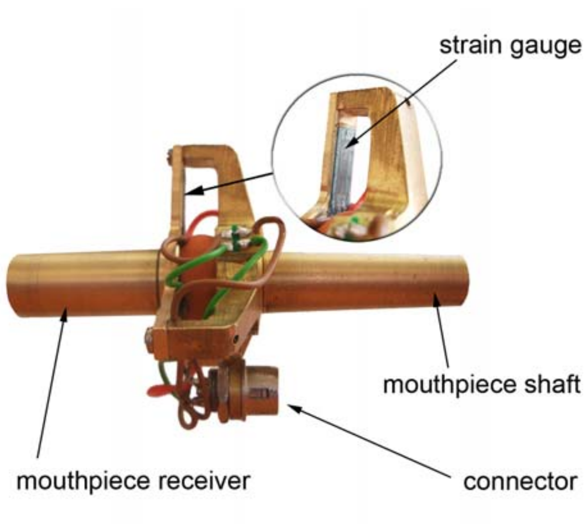

Fig. 6. Photo of the 3D-Transducer

Fig. 6 shows the fully assembled transducer and a detail view of one strain wing where the attached strain gauge is visible. In the first prototype only one strain gauge was mounted on each wing. Depending on the directional components of the force (Fx, Fy, Fz), the stress of each wing will vary in amplitude and sign.

3 TRILINEAR TO CARTESIAN COORDINATE CONVERSATION

Strain gauges are mounted on three radial wings around the mouthpiece axis at angles of 0°, 120° and 240° to the x-axes. The orthogonal force components Fx, Fy and Fz have therefore to be calculated using some coordinate

transformations. The z component can be derived as the sum of all measured force contributions $F_m a$, $F_m b$ and $F_m c$.
The calculation of the components x and y is not as obvious.
Fig. 7 shows geometrical relationships between the trilinear and the orthogonal system. Vectors are labeled in capital letters. A force F with a direction perpendicular to the z axis of the transducer will cause the partial forces $F_m a$, $F_m b$, and $F_m c$ to be measured by the strain gauges. In **Fig. 7** they are shown as orthogonal projections of the original force F.

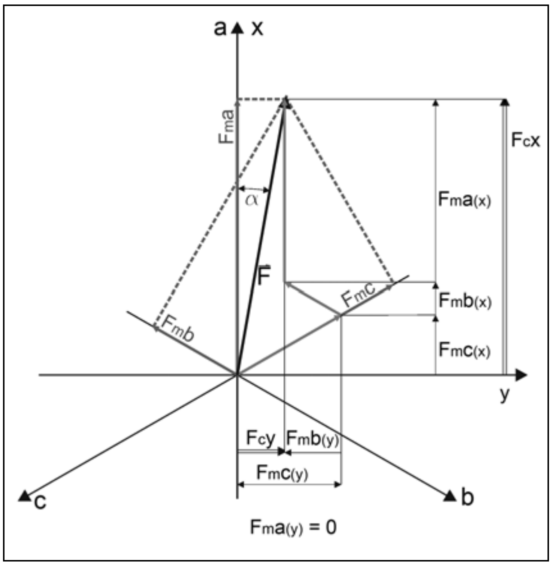

Fig. 7. force conversation into the x, y plane

The x and y components of the original force F as functions of the measured magnitudes $F_m a$, $F_m b$, and $F_m c$ can be derived from the relations:

$$F_c \begin{pmatrix} x \\ y \end{pmatrix} = F \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix}, \qquad (1)$$

and

$$F_m a \begin{pmatrix} x \\ y \end{pmatrix} = F \cos\alpha \begin{pmatrix} \cos 0^\circ \\ \sin 0^\circ \end{pmatrix},$$
$$F_m b \begin{pmatrix} x \\ y \end{pmatrix} = F \cos(120^\circ - \alpha) \begin{pmatrix} \cos 120^\circ \\ \sin 120^\circ \end{pmatrix}, \qquad (2)$$
$$F_m c \begin{pmatrix} x \\ y \end{pmatrix} = F \cos(120^\circ + \alpha) \begin{pmatrix} \cos 240^\circ \\ \sin 240^\circ \end{pmatrix}.$$

Unlike in the Cartesian coordinate system, in a trilinear coordinate systems the vectors $F_m a$, $F_m b$, and $F_m c$ are not linearly independent. The original force F is no longer equivalent to the sum of the projections of $F_m a$, $F_m b$ and $F_m c$ but proportional by a constant factor k:

$$F_m a + F_m b + F_m c = kF\ . \qquad (3)$$

Insertion of equations (1) and (2) into (3) yields a proportionality factor k of 3/2. The resulting force components can now be derived as

$$F_c x = \frac{1}{k} * \left(F_m a - \frac{1}{2} * (F_m b + F_m c)\right) \qquad (4)$$

and

$$F_c y = \frac{1}{k} * \frac{\sqrt{3}}{2} * (F_m b - F_m c). \qquad (5)$$

Taking into account that the force transducer resembles a trihedron, the values of $F_m a$, $F_m b$ and $F_m c$ have to be scaled according to the law of the lever:

$$F(d) * l_1 = F_m(d) * l_2, \qquad (6)$$

where l1 is the distance between the mouthpiece rim and the center of the strain element, and l2 is defined by the distance mouthpiece rim and the effective wing-radius. (see **Fig. 8**) The variable (d) in equitation 3 changes relating to the direction to a, b, or c, F(d) equals the (d)-component of the force produced by the player.

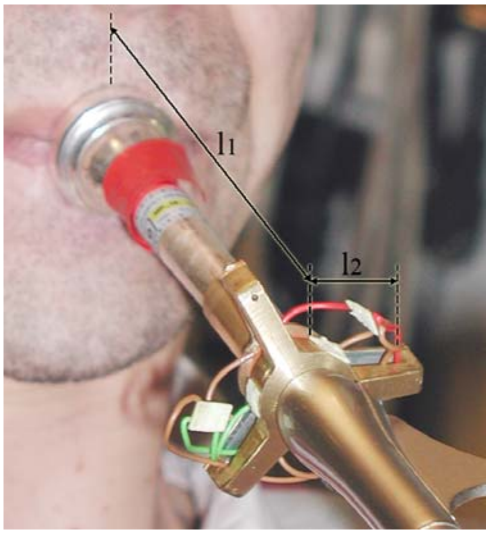

Fig. 8. Lever relations during playing

3.1 Signal conditioning and data acquisition

Electrically the strain gauges are part of three half bridges. A change of their resistances will therefore modulate the bridge currents. This results in proportional output voltage changes which are amplified to be forwarded to a three channel analog to digital converter. **Fig. 9** shows the block diagram of the measurement setup. As it is desirable to simultaneously capture the trumpet sound as a reference, the computer's soundcard channels have been dedicated to this purpose. The three transducer signals $F_m a$,$F_m b$ and $F_m c$ have been recorded using some external USB data acquisition system. The data acquisition software was programmed using National Instruments' software package LabVIEW.

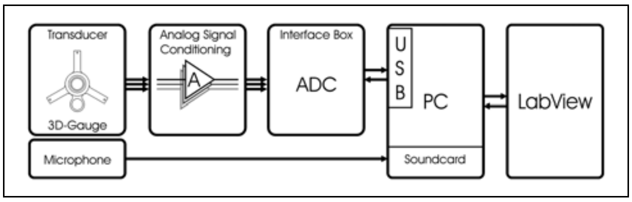

Fig. 9. measure setup block diagram

3.2 Data acquisition software

LabVIEW is a graphical development environment for creating flexible and real-time test, measurement and control applications. LabVIEW offers easy access to and control of peripheral data acquisition systems and soundcards. The functional diagram below (see **Fig. 10**) illustrates the operating principles of the created application. **Fig. 11** shows a screenshot of the application window.

After starting the program the software sets up the communication with the data acquisition device and the soundcard. Then a continuous 3-channel data stream originating from the data acquisition device is recorded by the software. Data samples are offset and gain calibrated using reference data from a calibration file. Offset re-calibration has to be initiated by the user by clicking the "0" switch when no external force is present.

During offset calibration the instrument should be held vertically with no additional load applied to the mouthpiece. Gain calibration is accomplished by putting known weights on top of the mouthpiece. These weights have to be entered in the "calibration weight" dialog. Calibration data can be saved in the calibration file in order to be available in future sessions. After calibration the system is ready to record sound and lip-force waveforms of a musician during an actual performance.

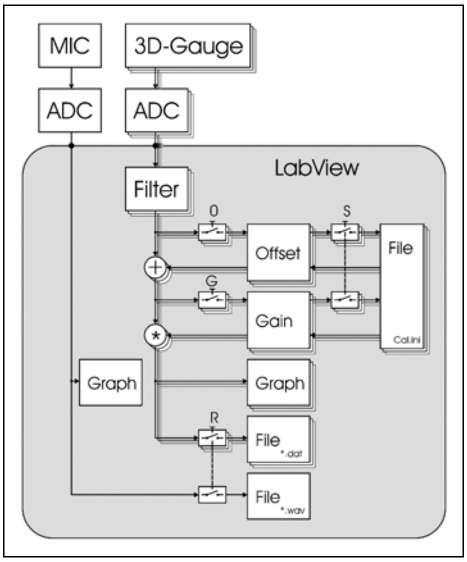

Fig. 10. Functional diagram of the data acquisition software

In the left plot window (refer to **Fig. 11**) the transducer signals F_ma, F_mb and F_mc are displayed in real time. The Cartesian force components Fx, Fy and Fz are shown in the right real time plot.

Pressing the "REC" button enables a sound waveform display and starts recording the sound- and 3D transducer data. These data are available in two separate files for further analysis.

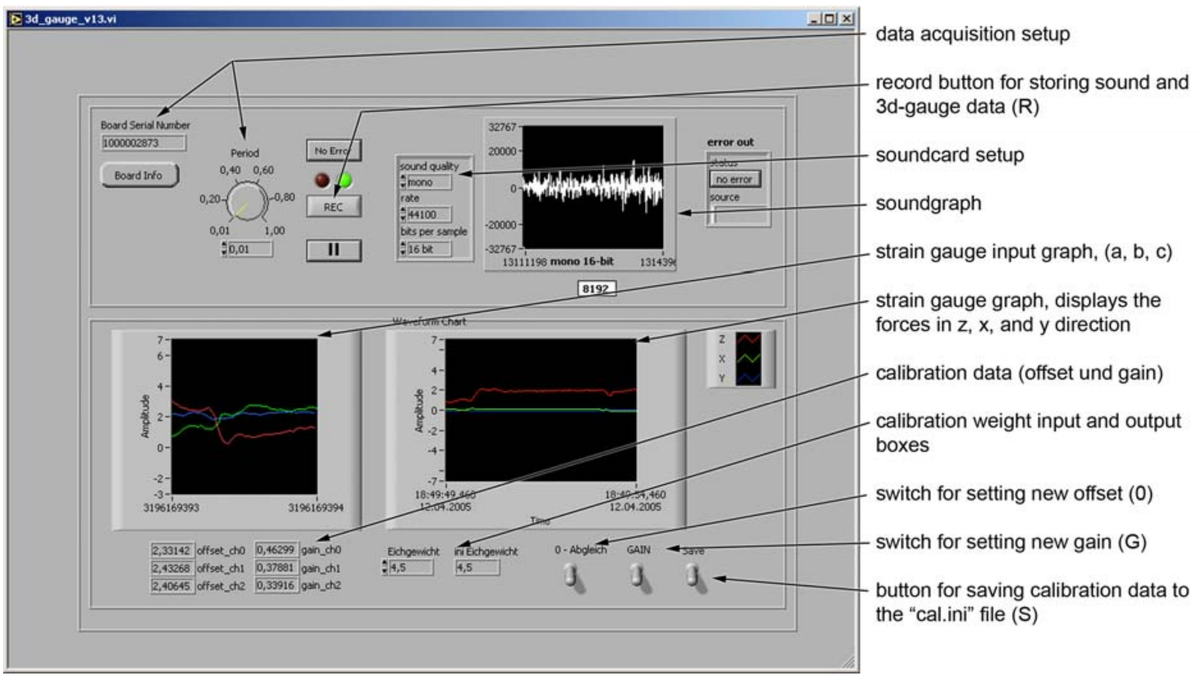

Fig. 11. Program window

4 RESULTS

First measurements by the authors have been made sucessfully. Resulting data have been analyzed and can be seen in **Fig.12** In the middle of the graphic, you can see the trumpet mouthpiece force on the lips measured with the 3D Transducer. The force on the lips is plotted as sum (Z:dark line) and for x and y directions (x:blue, y:yellow line). Above this, the corresponding music of the performed task is shown and below a spectrogram of the actually played task can be seen. The FFT reveals not only the partials of the trumpet sound, but also the Metronom clicks with a metrum of 60 bpm.

The force on the lips depends on the register and the dynamic. In the low and middle register, forces vary from 3-10 Newton. With the crescendo on the f#5 the force increases from 8N to 28N and the b5 even reaches forces of 40N when playd fortissimo. Last note in the example, B4 is the sounding a4 of 440Hz since a Trumpet in Bflat has been used.

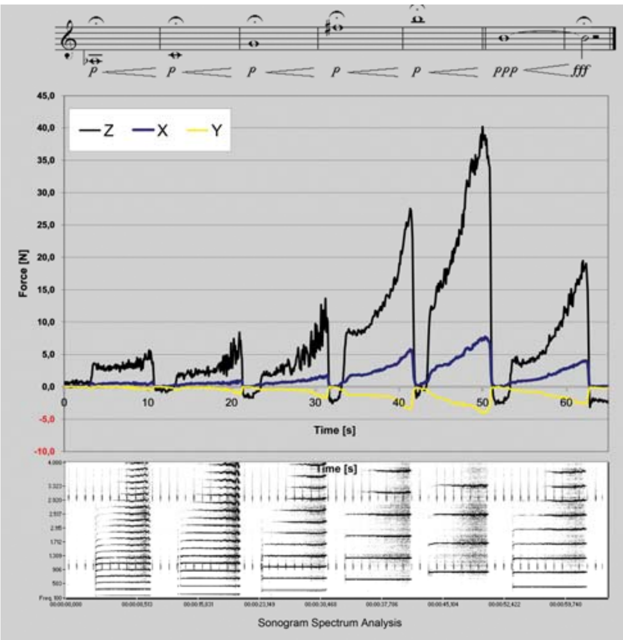

Fig. 12. Trumpet mouthpiece force on the lips measured with the 3D Transducer.

Currently the transducer increases the length of the instrument which lowers not only the tuning pitch of the instrument but also the intonation of individual tones. This is a drawback as it makes musicians feel uneasy during performance. They have to slightly change their posture and they might try to compensate for the changes of the acoustical characteristics of their instrument by adapting the embouchure.

Fig. 13 shows two acoustic impedance measurements made using the brass instrument analysis system BIAS [14]. The change of the instrument's resonance peaks by inserting the 3D force transducer can easily be recognized.

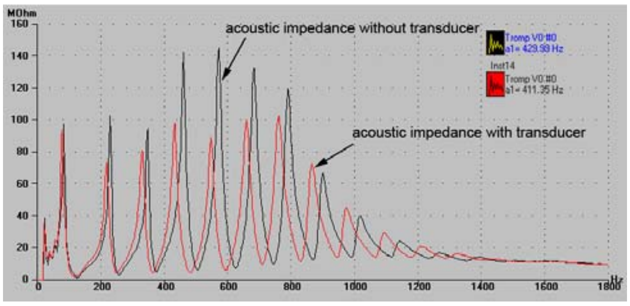

Fig. 13. Comparison of the acoustic impedances

All resonance peaks are still at a similar position. The intonation of all notes are altered and the playing characteristics are slightly changed (see **Fig. 13**). Future versions of the transducer geometry can be optimized using the BIAS optimazation features [14]. In **Fig. 14** the corresponding intonations are plotted.

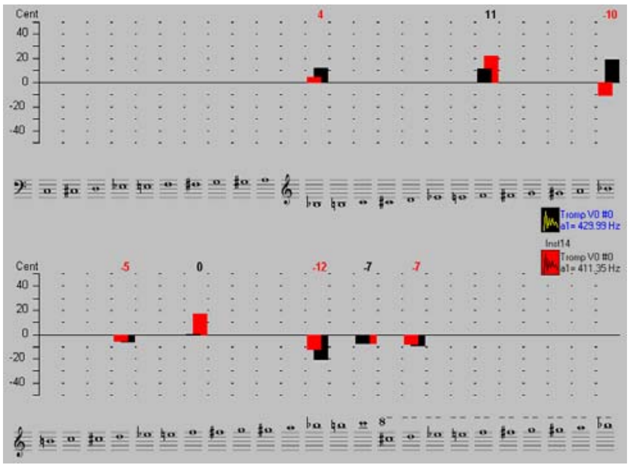

Fig. 14. Intonation plot

5 CONCLUSIONS

A consumer version of the presented prototype of a new 3D transducer could be a great tool for brass players and especially trumpet pedagogics. Feedback about the actual mouthpiece pressure and it directions can and will help players to find their individual best setup.

The measurement system is easily attachable to a personal trumpet – mouthpiece combination. The sensor adaptor has very little influence on the playing charateristics which can be reduced in further versions by BIAS optimazations.

It gives simultaneous feedback to the player and through the recording of the data, together with the recorded sound, performance studies are possible. A new feature is the measurement of the force in three dimensions. The sum function in Z direction correlates well with previous studies of Barbenel and Petiot.

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