RIAM 2.0 - REED INSTRUMENT ARTIFICIAL MOUTH: A BLOWING AND TONGUING DEVICE FOR ARTIFICIAL EXCITATION OF SINGLE-REED WOODWIND INSTRUMENTS

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ABSTRACT

This technical report provides the construction details and solutions of the further development of a reed-instrument artificial mouth (RIAM), which is an artificial blowing device used to analyse single-reed musical instruments. Among other aspects, the extension by a special seal, which flexibly encloses the mouthpiece, and the introduction of a controlled artificial tongue are discussed. Software developed in LabVIEW is explained for a better understanding of the features provided. Technical drawings presented should facilitate reproducing the design of RIAM 2.0.

1. CONTEXT

In the field of Music Acoustics, a so-called *artificial blowing machine* is a pneumatic setup commonly used to analyse the acoustics of wind instruments outside the musician's mouth. In such setups, the excitation of the instrument (i.e. a clarinet) is achieved by the control of pressurised air in a closed cavity called 'artificial mouth'. After the first blowing machines presented by McGinns and Gallaghe [1] and Backus [2], different approaches have been implemented to control the blowing pressure and achieve steady oscillations of single-reed woodwind instruments [3]. In order to identify the oscillatory characteristics of single reeds, artificial blowing machines with pressure control [4, 5, 6, 7, 8] served, for example, to characterise the pressure–flow relationship when testing different pressure profiles and lip forces [9, 10, 11]. Later setups included an artificial tongue system, either as part of a robotic player [12] or as an on-off actuator using a static load [10, 13, 14].

In the years 2015 until 2019 motivated by the research on the acoustics of single-reed woodwind instruments in the Department of Music Acoustics – Wiener Klangstil (IWK) of the mdw - University of Music and Performing Arts Vienna,

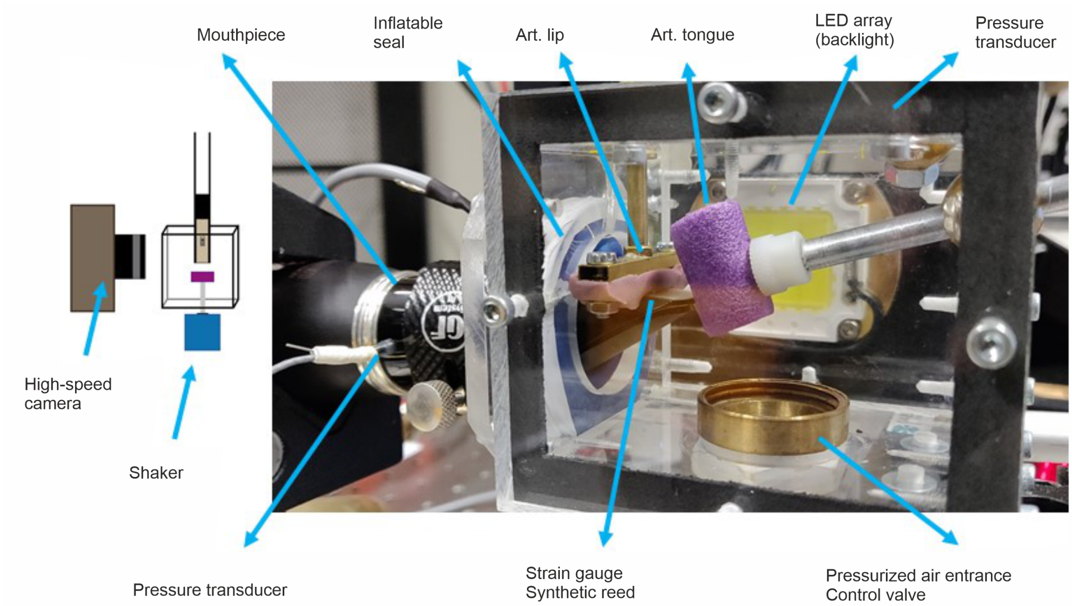

Figure 1: Components and measurement devices of the artificial blowing-and-tonguing machine. Air pressure and lip force can be adapted. A LED array as backlight provides a light source for sharp and contrast rich recordings with a high-speed camera.

an artificial blowing and tonguing device was designed and built. Similar to a previous design [7], the setup is based on the accurate control of the air pressure in a cavity, while transparent walls allow observing the reed motion. The device is equipped with an externally-controlled artificial tongue (Figure 1). This setup enables the calibration of sensor-equipped single-reeds [15], which can be used for the analysis of clarinet playing techniques [16, 17]. Clarinet blowing and tonguing techniques were reproduced in the blowing machine [18] and were compared with a physical model [19]. This blowing machine was also used to analyse 3D-printed saxophone mouthpieces [20].

2. HARDWARE

In the following sections, the function and construction of the artificial blowing machine will be discussed. Particular attention is paid to the special features, such as the inflatable sealing ring and tonguing system.

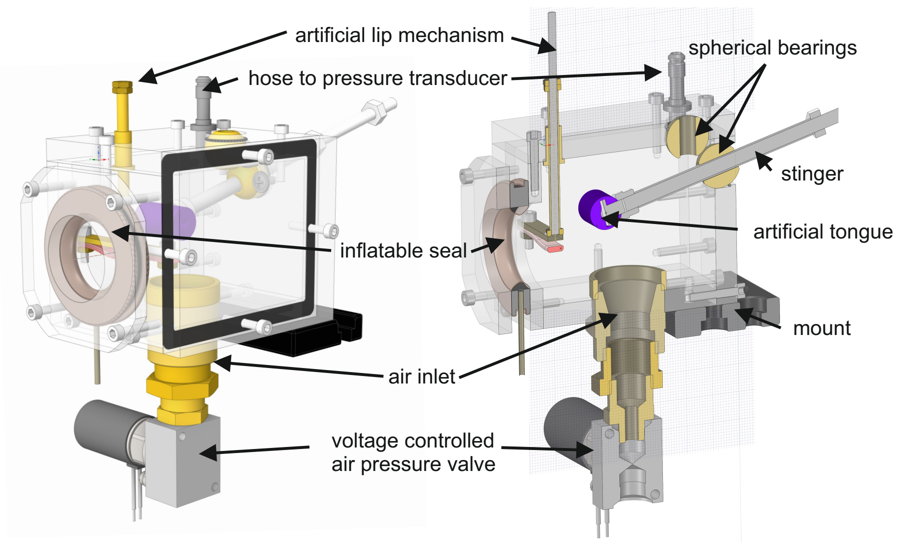

Figure 2: 3D sketch of the blowing-and-tonguing machine together with a vertical cut to observe the interior of the components

2.1. Artificial mouth: air pressure control

The artificial mouth is a 170 cm^3 transparent *plexiglas* box. It contains an artificial lip and two spherical bearings from which an artificial tongue can enter the cavity from two different positions (Figure 2). Three faces of the transparent box are clear to allow a free view of the reed and mouthpiece. The mouthpiece of a single-reed woodwind instrument is inserted through a special pneumatic component that provides an airtight seal. A standard workshop air compressor is used as source of pressurized air. A voltage-controlled valve (SMC; type PVQ33-5G-23) is mounted below the *plexiglas* box, between the artificial mouth and the air compressor.

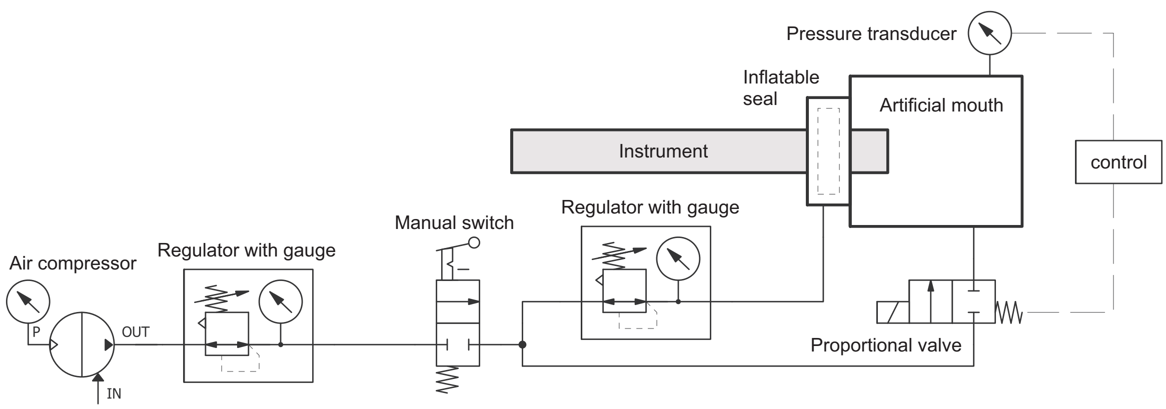

Figure 3: Diagram of the pneumatic circuit controlling the air pressure in the artificial mouth and the inflatable seal

The pneumatic circuit is set as presented in Figure 3. At the *air compressor*, a pressure *regulator with gauge* limits the air pressure entering the circuit. Between the compressor and the proportional valve, there is a *manual switch*, which can be used as an emergency security valve to stop the air flow and reduce the air pressure in the system. From this switch, the air hose splits into two lines. One line is used for the *inflatable seal* via a manually-adjustable *regulator with gauge*. The other line delivers pressure for the artificial mouth. The connected *proportional valve* is computer-controlled. A *pressure transducer* (Technoterm 5400) provides a readout of the measured air pressure in the artificial mouth, as well as an analogue voltage output. This signal is used both for recordings and within the feedback loop to control the proportional valve (see Section 3.1).

2.2. Artificial lip

The lips of a single-reed woodwind player have two main functions: to interact with the reed (adjust the vibrating length, damping, lip force...) and to seal the mouthpiece airtight in the mouth. In the proposed setup, these two functions are treated separately. On one hand, an artificial lip in the artificial mouth directly contacts the reed (Figure 1) and, on the other hand, a pneumatic inflatable seal surrounds the mouthpiece between the ligature and the Plexiglas box (Figure 4).

An artificial lip is mounted inside the artificial box, next to the box orifice where the mouthpiece is inserted (see Figure 1). Since the instrument is inserted with the reed facing upwards, this lip mimics the lower lip of the player. It consists of a brass bar with a silicone overlay (see technical drawing, Sheet 2 of 2, Lip mechanism). Only the overlay is directly in contact with the reed. The mechanism is mounted on a translation stage, that allows to set its vertical position (Figure 2). The control of the reed–lip relative position is achieved by adjusting the position of the mouthpiece in the mouth, i.e., by how much the instrument enters the artificial mouth. On the translation stage, a strain-gauge provides a vertical force measurement. This value was used only for monitoring initial forces, but not in a feedback control as in the previous setup [7]. If the lip-reed contact force is also to be integrated into the control loop, the system can be easily adapted mechanically and in terms of software.

2.3. Inflatable seal

Due to the shape of the clarinet and saxophone mouthpieces, it is not possible to create simple seals to the artificial mouth. One possibility is to seal the instrument at the rotary symmetrical barrel [7]. Although this is simple, it increases the air volume of the artificial oral cavity, which in turn has a disadvantageous effect on the automatic regulation of the blowing pressure. This is remedied by a sealing ring that flexibly encloses the mouthpiece like the lips of a human player. A construction with these properties is the so-called inflatable seal. The actual sealing body is made of an expandable material like rubber or latex. By increasing the internal pressure, the inner diameter and shape of the seal adapts itself around the mouthpiece (Figure 4).

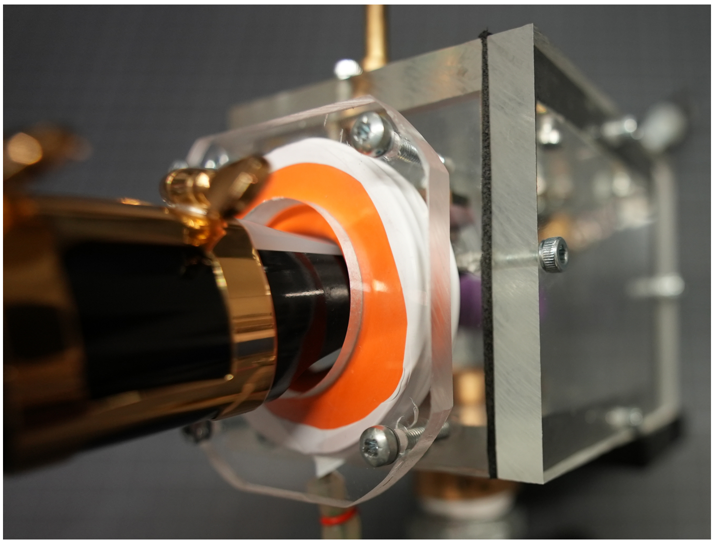

Figure 4: The inflatable seal provides an airtight fit also for uneven objects

As there is no affordable industrial product for the large diameter variations required, a custom design was developed. The mechanical parts are shown in detail in the technical drawing attached to this report (Figure 11). Basically, the seal consists of a ring that is covered with a flexible and stretchable material. An air duct allows air to enter the inside of the ring. When this assembly is installed, the air pressure causes the material to expand only inward, enclosing the object to be sealed. For the system described here, a simple, strong balloon served as source for the flexible material. The ring was by that time machined out of POM (a thermoplastic used for CNC machinery), yet modern 3D-printing technologies can of course be used instead.

2.4. Tonguing system

As shown in Figures 5 and 6, the artificial tonguing system consists of three parts: a cylindrical piece of foam, a shaker-stinger (by PCB) and a shaker (SmartShaker by PCB; type TMS-K2007-E01). The tongue is made out of cellular polyethylene foam ($2.2 \times 1.3 \times 1.3$ cm^3), providing damping of the reed vibration when the tongue–reed contact happens. The PCB shaker-stinger enters the box via a lateral spherical bearing (see detail in Figure 2). The movement of the tongue follows the oscillations of the computer-controlled shaker towards and backwards from the reed tip. The tongue positioning in the mouth is finely controlled with a translation stage where the shaker is attached (Figure 5). A mechanical impedance sensor (PCB; type 288D01) is placed between the stinger and the shaker to monitor its acceleration. The tongue motion describes a pattern that is computer-controlled (via LabVIEW software, see Figure 7) to achieve several articulation techniques.

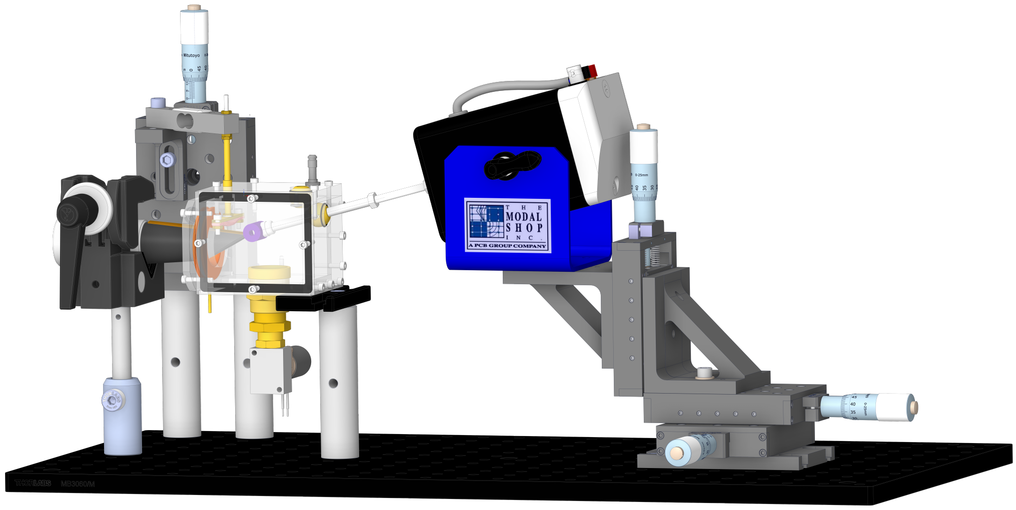

Figure 5: 3D sketch of the blowing-and-tonguing machine including shaker, mounted on a breadboard (e.g. Thorlabs MB4560/M) together with translation stages (Thorlabs PT3A/M).

Moreover, the spherical bearing allows adjusting the position and inclination of the tongue in the artificial mouth, while it provides two main playing configurations. The tongue can reach the reed from above, following a transverse motion to the clarinet axis, or it can reach it from the top, following the clarinet's longitudinal axis (Figure 6). For the analysis of tongue articulation in an artificial blowing machine, these two approaches for the tongue motion were tested. In the longitudinal approach, the tongue and the shaker are set to move in the direction of the clarinet axis, reaching the tip of the

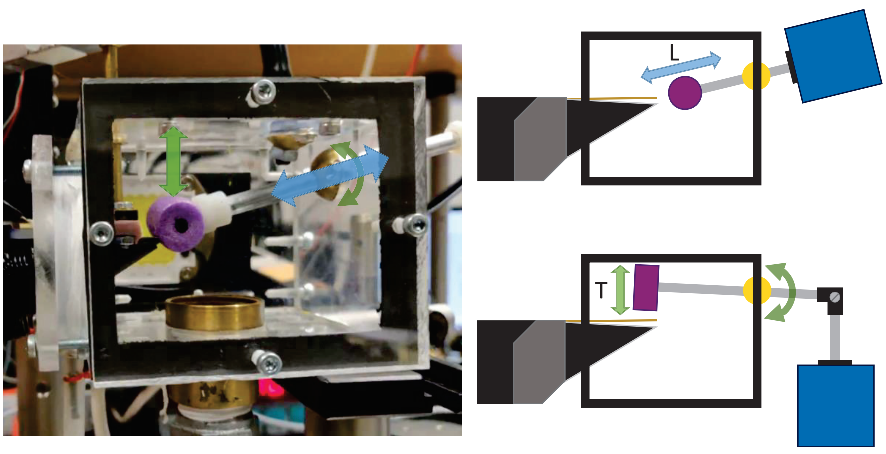

Figure 6: Left: Image of the artificial tonguing setup seen from the front. Right: scheme of the setup in two configurations: longitudinal (L) and transverse (T) tongue motion.

reed (L in Figure 6). In this case, the spherical bearing is fixed, and the rod moves through it, in the direction of the axis of the shaker. In the transverse approach, the shaker axis is placed vertical on the breadboard and a 3D-printed plastic joint is included between the shaker axis and the rod supporting the tongue (T in Figure 6). This way, the rod gently sets the spherical bearing to rotate, and the tongue moves transverse to the axis of the clarinet, meeting the tip of the reed from the top.

3. SOFTWARE

The control software was implemented in National Instruments LabVIEW 2011. Data Acquisition (DAQ) devices from the same manufacturer can easily be embedded. For the described setup, two NI PCIe-6351 DAQ cards are used in parallel. One device is used to serve the PID air-control as well as the signal for the tonguing system. The second device is used only as input for recording values of interest into a multichannel sound-file. Figure 7 shows the graphical user interface (GUI).

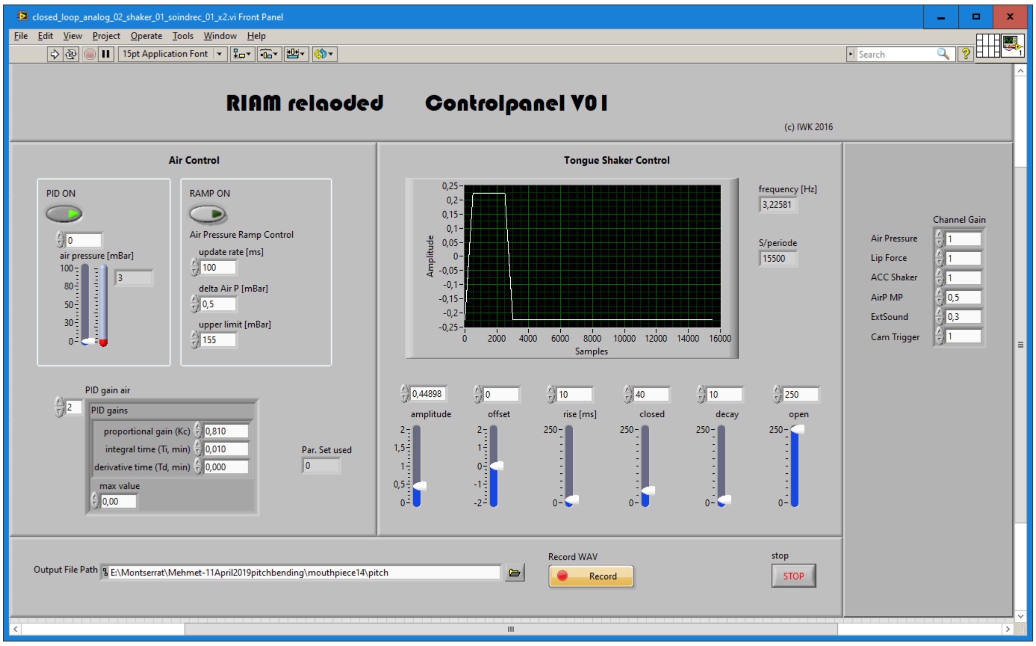

Figure 7: GUI programmed using NI LabVIEW: PID Control for setting air pressure, pressure ramp control, shaker signal designer and waveform controller

3.1. PID control

The closed-loop control of the artificial mouth poses an interesting and challenging task. On the one hand, relatively high values of delay in building up the desired air-pressure have to be expected due to the limited amount of air to fill the cavity. On the other hand, the system response deteriorates depending on the embouchure parameters (lip position, lip contact force and reed-tip opening). Also, the transition from the resting to the steady-state vibration of the reed changes the response characteristic of the system. Therefore, a simple PID control must respond very slowly or a more complicated algorithm must be chosen. [21]

A middle course was taken here. Depending on the difference between set point variable and measured value of air-pressure inside the artificial mouth cavity, different parameter sets are called up for the PID control loop (see Figure 8). In order to keep the reaction delay caused by the digitisation of the measured variable to a minimum, the sampling is done at 50 kHz sampling rate and a buffer size of 1 sample. Ideally, the delay caused by the DAQ system and digital control is about one sample length, what result in an average response time of 0.02ms.

3.2. Air pressure ramp control

For analysing reed-oscillation thresholds, a simple “air pressure ramp generator” could be used. In the “Air Control” section in the GUI (see label “Air Control” in Figure 7) the user can set values for update rate, pressure step and upper limit. It should be mentioned that the value for the pressure step (“delta Air P”) is an estimation, as the PID-control is switched off during this program mode. The set value corresponds to an output voltage step which is fed to the electromagnetic valve directly.

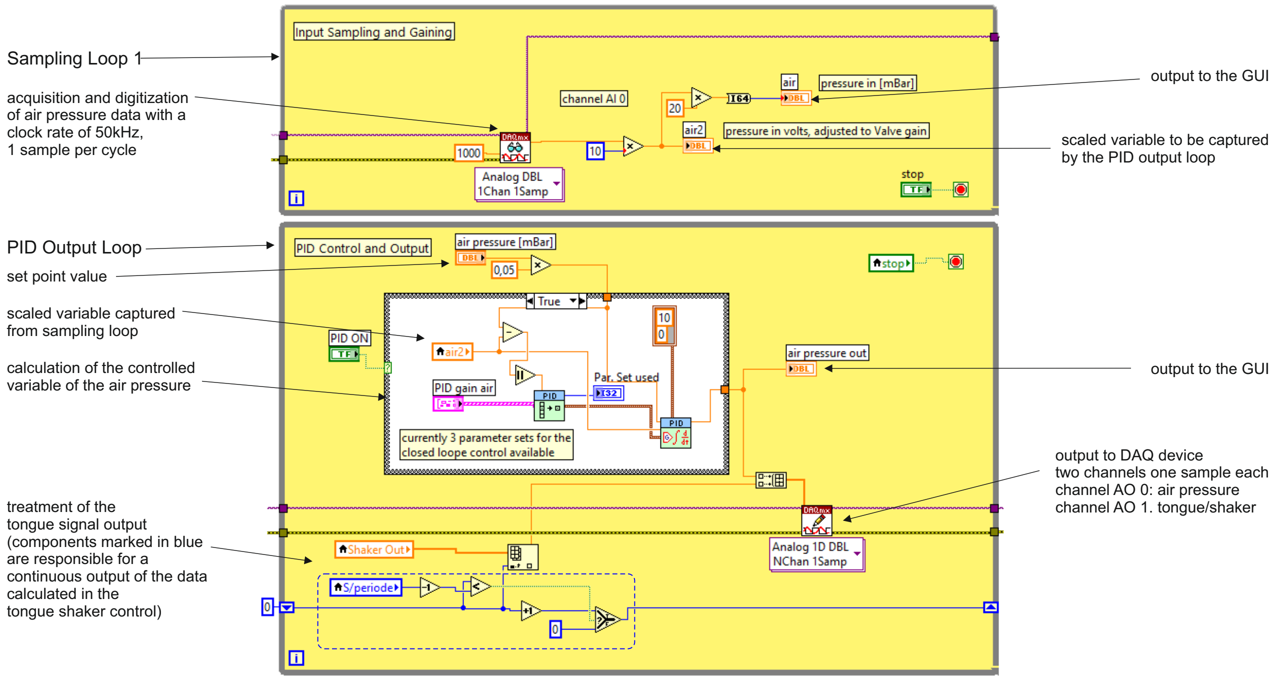

Figure 8: Sampling and PID control loop: practical tests indicated better stability when the loops for input sampling and output control are independent (the yellow sections indicate separate while-loops). Since the pressure transducer for measuring the pressure inside the cavity has a built-in low-pass filter, digital smoothing could be omitted.

3.3. Tongue shaker control

The shaker that moves the tongue in the artificial mouth is programmed using a simple waveform generator (see "Tongue Shaker Control" panel in Figure 7). A set of four temporal control variables, named "rise", "closed", "decay" and "open", allows designing the tongue movement, while the signal output amplitude can also be adjusted. Depending on time values set, signals like rectangular, triangle, saw-tooth or any type in between can be designed. The "rise" corresponds to the movement towards the reed, and "open" moves the tongue away from the reed. For instance, setting "rise" (0-250 ms) moves the tongue into the direction of the reed/mouthpiece, according to the chosen amplitude. All other time values can also be set to values between 0 and 250 ms. Therefore, it results in the slowest programmable motion of a periodicity of 1 Hz. From our experience of working with the PCB-shaker, signals below this frequency will not be reproduced in full detail by the shaker. This is due to the high-pass-filter of the integrated power-amplifier of the shaker. An additional input control for setting a signal offset can be used if needed. The generated signal will be output sample per sample together with the air-pressure control value at a sampling rate of 50 kHz.

3.4. WAV recording

As mentioned before, two DAQ devices are used in parallel. One handles the air-valve and shaker signals with a buffer size of 1 sample. The other device is used to record a multichannel sound file. In this case, six signals can be recorded with a sampling rate of 50 kHz. For handling recordings of large amounts of data on hard-drives, the device was set to use a buffer size of 5000 samples. For a better use of the dynamic range of the sound file, the user can set a gain for each channel separately (right-hand side of Figure 7). Due to the simple software architecture, the number of channels to be recorded can be easily expanded up to 16.

4. CONCLUSIONS

The device and software for the updated reed-instrument artificial mouth (RIAM 2.0) presented in this technical report have proven its performance for several research endeavours [15, 17, 19, 20]. The automatic tonguing system led to a wider range of possible analyses, including studies on articulation [18]. The introduction of the inflatable seal offers an airtight and a flexible seal of the mouthpiece inside the cavity.

For a better understanding of the whole setup used, the 3D sketches 2 and 5 provide insights and build details. In the appendix, the technical drawings of the artificial oral cavity are included. The 3D drawings as step-files and the LabVIEW software as vi-files will be available online.

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6. APPENDIX

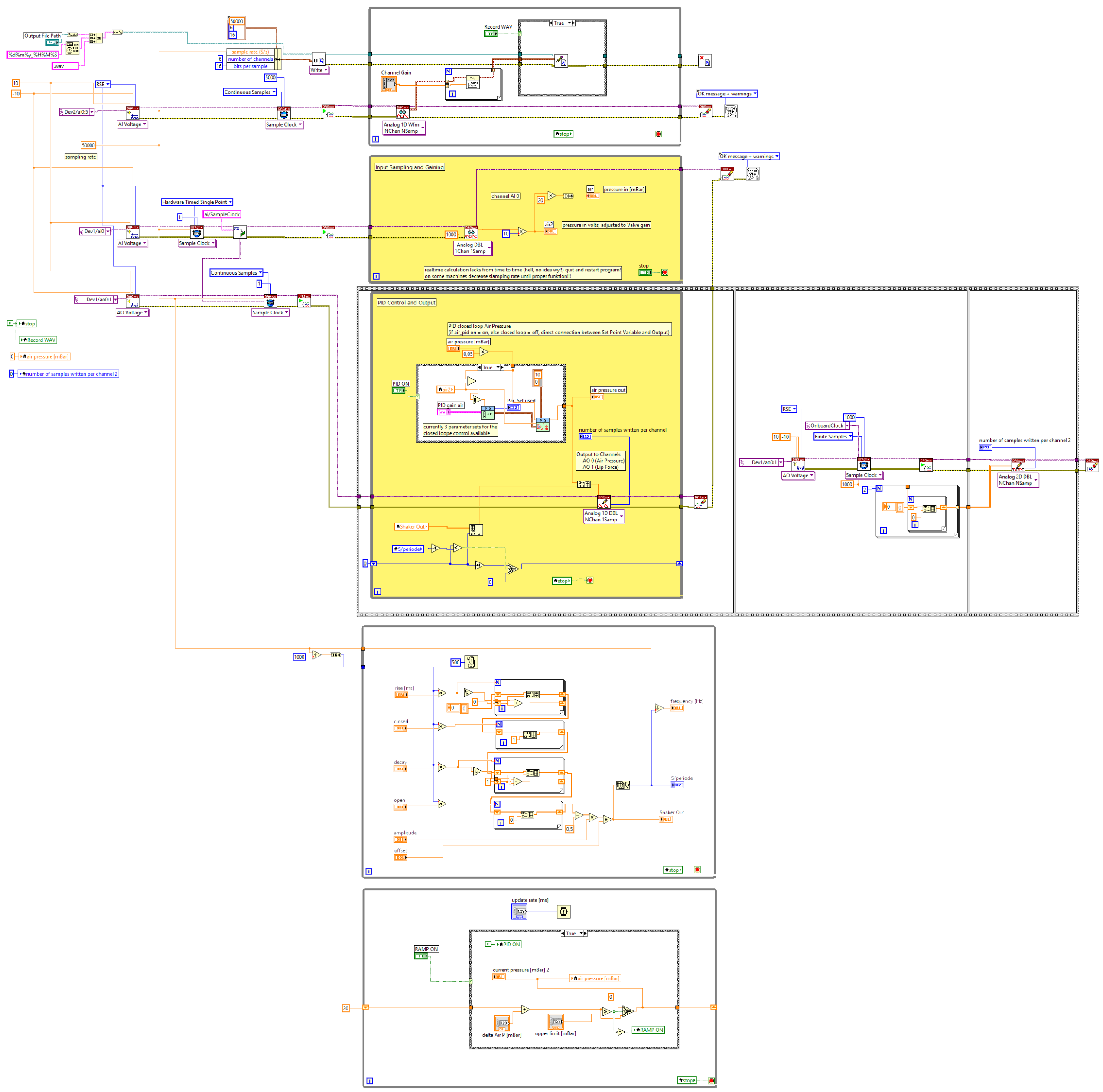

Figure 9: Overview of the whole LabVIEW VI, loops from top to bottom: sound-file recording, one sample input collection, PID control and 1 sample output, tongue signal designer, air ramp control

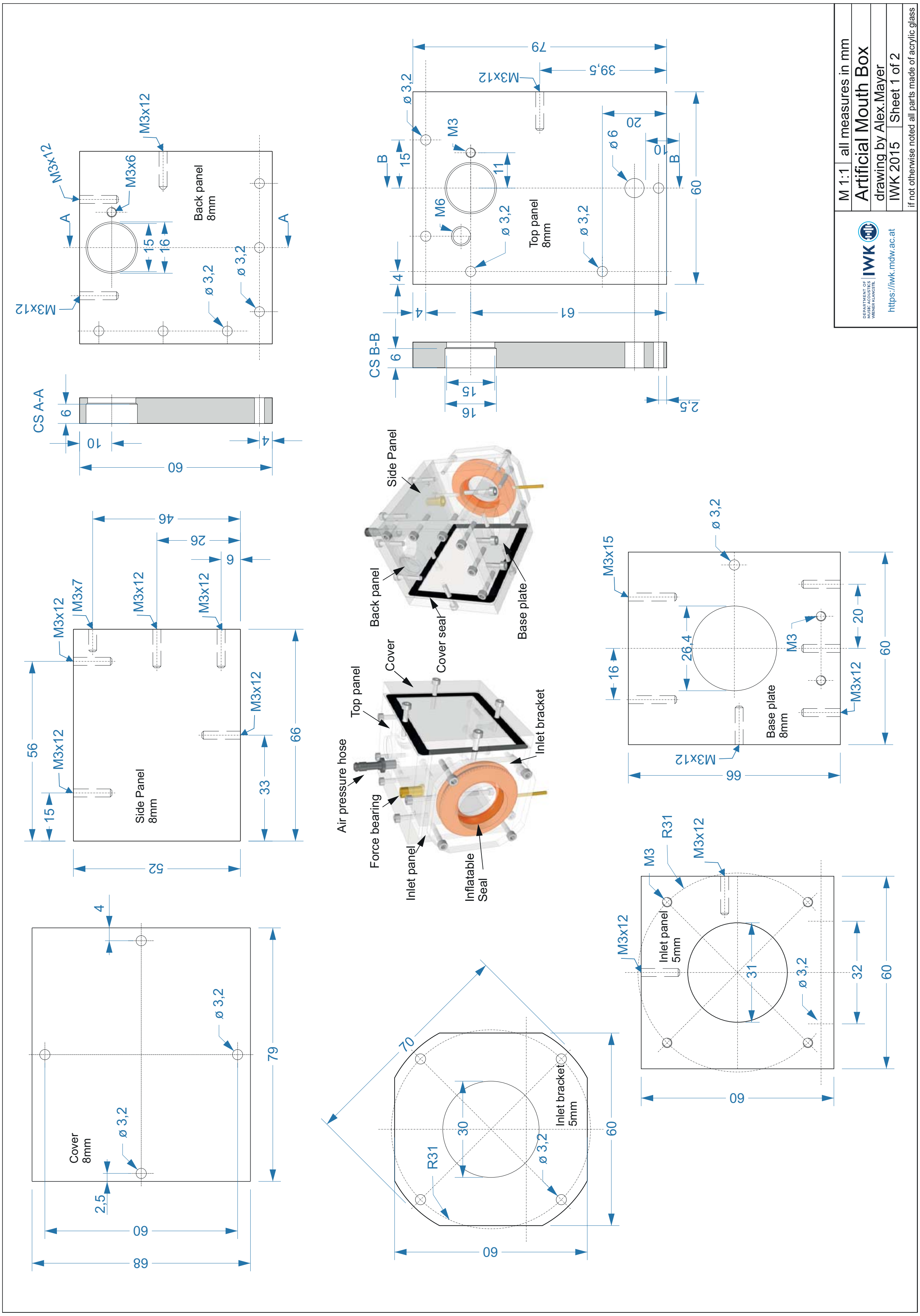

Figure 10: Technical drawing 1 of 2

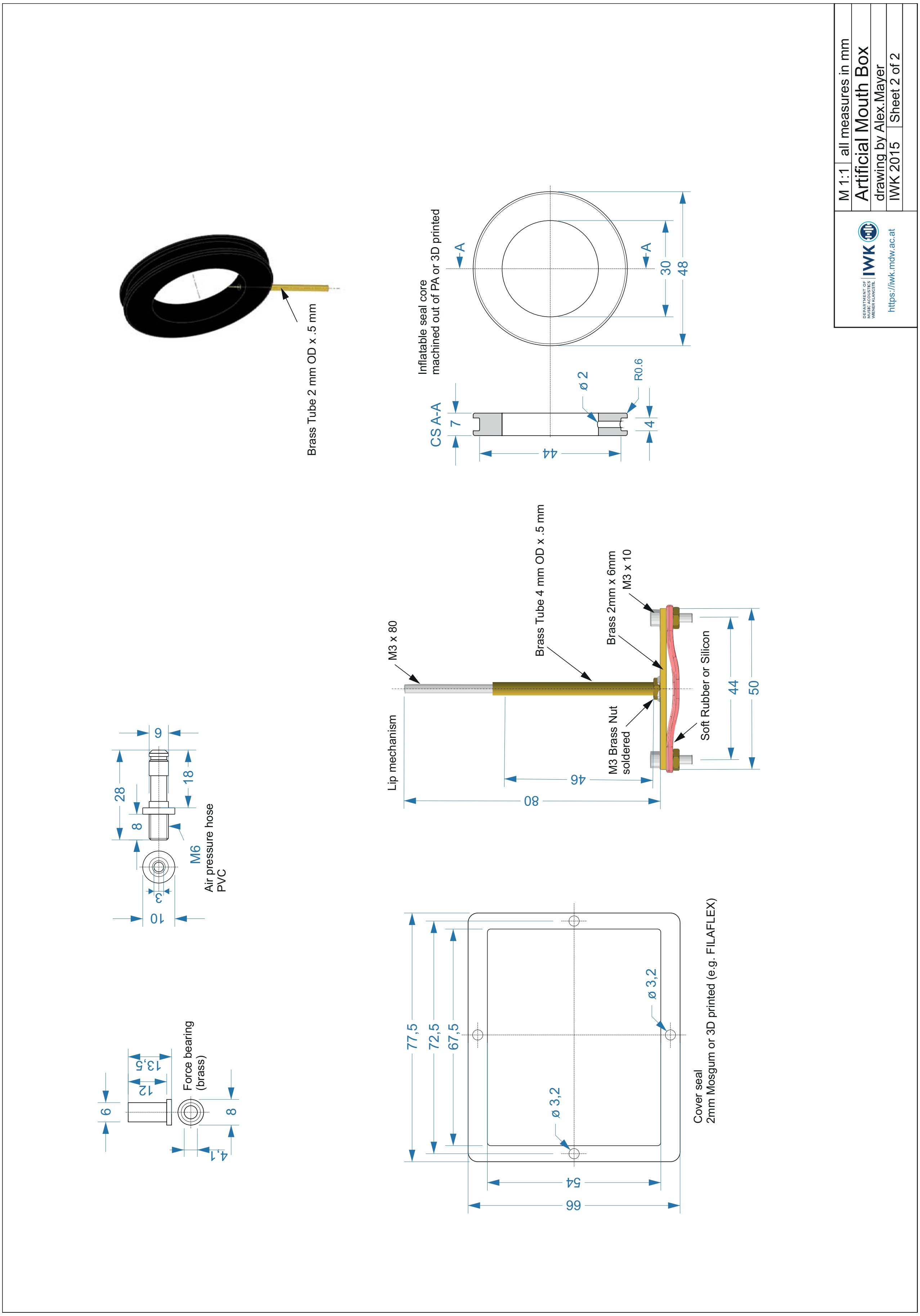

Figure 11: Technical drawing 2 of 2