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J. Stepánek, Z. Otcenášek. Acoustic documentation of 12 pipe organs and analysis of their plena. Journal de Physique IV Proceedings, 1994, 04 (C5), pp.C5-645-C5-648. 10.1051/jp4:19945139 . jpa-00252816

HAL Id: jpa-00252816

<https://hal.science/jpa-00252816>

Submitted on 1 Jan 1994

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Acoustic documentation of 12 pipe organs and analysis of their plena

J. ŠTĚPÁNEK and Z. OTČENÁŠEK

VUZORT a.s., Plzeňská 66, Praha 5, 151 24, Czech Republic

Abstract: The method for acoustic measurement and documentation of pipe organs developed in 1991 in VUZORT, Prague enables to describe the sound of all organ pipes and plena measured in situ. The real time measurement and digitalisation of the sampled sound, computation and processing of the amplitude spectrum are possible without necessity of sound recording. Sampling frequencies were adjusted to the stop length and fundamental frequency of the measured tone. The results of factor analysis of the octave spectra of Great organ plenum for 12 instruments are described. The Czech Baroque organs created a distinctive group in 3-dimensional factor space due to their rich harmonic spectra.

1. INTRODUCTION

There is a large number of pipe organs in the Czech Republic. Many rare historical instruments from the Baroque period have kept their original specification of stops. The sound documentation is important to rescue the original sound character of old instruments. In 1991 and 1992 we have developed the method for acoustic measurements of organs aimed at documentation of the sound of historical instruments.

2. DOCUMENTATION METHOD

The acoustic documentation of organs according to our method [1] involves several types of measurement. The in situ measurement has been chosen for the organ sound documentation, thus the influence of the room acoustics is fully involved. The measurement equipment is based on a personal computer, completed with a DAP board involving a signal processor. The real time measurement and digitalisation are possible without necessity of sound recording. The base of the sound documentation is the measurement of the quasi-stationary part of the tones for all stops (registers) and plena. Following Lottermoser's ideas concerning organ plenum measurements [2] the triads of neighbouring semitones sounding in the same time are measured. Acoustic pressure levels are picked up by three microphones placed in the typical listening position in a church. A mean amplitude spectrum calculated in the real time as well as the time signal of the first microphone are saved. The accuracy of measurement with three microphones is discussed in [1].

For the measurement of steady-state parts of tones we have defined the sliding sample rate which is not only adapted to the stop foot length, but changes fluently following the fundamental frequency of each triad. The spectrum contains the same number of partial tones for all triads. The sliding sample rate enables a well arranged graphical representation of results (see Fig.1 concerning the Mundt organ in the Church of Our Lady before Tyn, Prague).

3. ANALYSIS OF THE PLENUM SOUND

3.1. Analysed data

The list of the instruments documented with VUZORT method is shown in the Table I. The instruments 1 to 8 represent a group of Baroque organs with original pipes and specification. The Baroque instruments 9 and 10 have been substantially reconstructed in 1992, the new instrument in Most (11) and the instrument 12 are new designed organs in which contemporary scaling and voicing principles were applied. We have chosen the **plenum spectra of Great organ** to evaluate the organ sound because the plena reflect both the builder's design ideas and the room influence in the large extent. The composition of stops of the investigated plena is shown in the Table II.

The keyboard compass of Baroque instruments is mostly from C to c3. Using our way of the measurement of the stationary tone part, we have got 16 triads, which describe the sound in the octaves C, c, c1 and c2. Sound pressure levels calculated in five octave-bands (see Table III) were the input data for the analysis.

3.2. Factor analysis of 12 Great organ plena

We used the **factor analysis model (FA)** [3] for the statistical processing of the spectral data. FA is a mathematical method, through which a larger number of variables describing various object properties is substituted by the smaller number of new variables - factors. We used the principal component method and varimax rotation.

We applied the FA model on the levels calculated in five octave-bands for each of sixteen tonal triads in twelve investigated plena as well as on the averages of spectral levels of four subsequent triads belonging to the same octave. Thus, each instrument was represented by four "absolute" spectra. The averaging of the level values through four octaves mentioned above make possible to **represent each instrument by a "relative" spectrum**, expressed by means of five level values. These spectra were also processed by means of FA. The results have been found similar in all three cases and have led to a three-factor solution. The explained variance was 97.7% in the last case. All these results are in a good agreement with the results of an earlier work made by Plomp [4]. The connection of the "relative" octave-bands with the factor loadings and the percentage of the explained variance are shown in the Table IV.

3.3. Discussion

The first factor depends both on the amplitude of the higher harmonics and the frequency extent of the plenum spectrum. The second factor is determined by the middle part of spectrum. The third factor depends, above all, on the first harmonic of the plenum, i.e. of the Open Diapason. The obtained factor space of the investigated plena is shown in the Fig.2. The first factor coordinate was positive in Baroque instruments (except of the small organ on the side gallery in the St. Nicholas Church, which had an extremely weak sound) and negative in four "modern" instruments. Consequently we can say that the **Great organ plena of the Czech Baroque organs had richer harmonic spectra than the modern instruments**. This conclusion agrees well with the results of Plomp [4] who compared South and North German Baroque organs with modern instruments.

4. CONCLUSIONS

The used FA model has proved, that the results of the documentation measurement method which was described above constitute a good base for the future organ sound research. The possible comparison of "ideal" Baroque organ sound, typical for different regions or builders, with the sound of modern instruments could provide a common space of organ plena, in which the position of individual styles could be observed.

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Table I. List of documented organs and plena under research.

Place	Church / Hall	Builder	Year	code
1 Praha	P.Marie před Týnem	H.H.Mundt	1673	TYN
2 Český Krumlov	U P.Marie	N.Christeindel	1682	KRU
3 Praha	sv. František	A.Starck	1702	FRA
4 Polná	Nanebevzetí P.Marie	J.D.Sieber	1702	POL
5 Ždár n. Sáz.	Nanebevzetí P.Marie	J.D.Sieber	1723	ZDA
6 Dub na Moravě	proboštský chrám	J.Výmola	1769	DUB
7 Žlutice	sv.Petr a Pavel	F.P.Noli	1775	ZLU
8 Praha	sv.Mikuláš	T.Schwarz	1788	MIK
9 Most/small organ	Gothic (transferred)	V.Starck	1741	MMO
10 Most/main organ	Gothic (transferred)	V.Starck	1741	VMO
11 Most/new organ	Gothic (transferred)	Rieger-Kloss	1992	BMO
12 Praha	Rudolfinum	Rieger-Kloss	1974	RUD

Table II. Composition of Great organ plena.

Plenum code	TYN	KRU	FRA	POL	ZDA	DUB	ZLU	MIK	MMO	VMO	BMO	RUD
Open Diapason 8'	+	+	+	+	+	+	+	+		+	+	+
Coppel Flute 8'									+			
Octave 4'	+	+	+	+	+	+	+	+	+	+	+	+
Twelfth 2 2/3'	+	+	+	+	+	+		+	+	+		+
Fifteenth 2'	+	+	+	+	+	+	+	+	+	+		+
Flute 2'											+	
Nineteenth 1 1/3'	+	+		+			+	+	+			
Twenty-second 1'	+			+				+				
Mixture 2'			VI							VI		V-VI
Mixture 1 1/3'				V	III	VI		IV			IV-V	
Mixture 1'	VI	IV					III		III			IV
Cimbel 2/3'	IV			III								

Table III. Octave-bands (frequencies in Hz).

Tone\Oct:	1	2	3	4	5
C - H	64- 128	128- 256	256- 512	512-1024	1024- 2048
c - h	128- 256	256- 512	512-1024	1024-2048	2048- 4096
c1 - h1	256- 512	512-1024	1024-2048	2048-4096	4096- 8192
c2 - h2	512-1024	1024-2048	2048-4096	4096-8192	8192-16384

Table IV. Factor loadings for the "relative" octave-bands.

octave band	f1	f2	f3
1			0.90
2		0.79	0.51
3	0.70	0.61	
4	0.78	0.55	
5	0.92		
% of variance	42.6	28.8	26.3

Fig.1. Graphical representation of an organ plenum sound documentation.

Fig.2. Resulting factor space of the analysed plena.