Adrian v. Steiger/Martin Tuchschmid/Rainer Egger

The German Trombone. Aspects of Its Materiality

Historically informed performance is largely focused on musicological insights and period instruments. These instruments can be manufactured using both materials and manufacturing techniques from the period in question. As previous projects on brass instruments have shown, more research is needed into historical brass alloys, manufacturing procedures, wall thicknesses and technical details. For its research on German trombones of the nineteenth and early twentieth centuries, this project involved a multidisciplinary collaboration between the Bern Academy of the Arts HKB, the instrument maker Rainer Egger, Basel, and the natural scientists of Empa (the Swiss Federal Laboratories for Materials Science and Technology) in Dübendorf. In a second step, "The Sound of Brass" entered into questions of acoustics: If we build copies of period instruments using historical manufacturing techniques, what impact does this have on their playing characteristics and, ultimately, on their sound? And can we measure this impact?[1]

If we are to acquire an understanding of the German trombone, then it is of particular importance that we understand certain aspects of its materiality. This is primarily because we cannot produce faithful replicas without such knowledge,[2] *but also because its materiality was discussed controversially in the past.*[3] *The present research project investigated a number of historical trombones*[4] *under three aspects: 1) the chemical composition of the brass used for all their parts; 2) the wall thicknesses of all their parts; and 3) their geometry and technical features. This paper presents the conclusions drawn from those investigations.*

The characteristics of the German trombone

What is a 'German' trombone (often referred to as a 'Leipzig' trombone, which is actually a more accurate name)? What are its characteristic parameters? It is our hypothesis that its principal characteristic is a dark, vocal sound. A catalogue of the period states "Conical throughout. Fabulous soft and full sound".[5] The goal of all its features is to produce just such a sound by means of:

- a large bore, ca 13.5 mm for tenor trombones;
- conicity throughout the instrument, also in the slide (nearly 50% of the project's historical instruments have a conical slide);

1 See also Zemp et al. 2019.

2 See the articles of Rainer Egger and Alex Schölkopf in this volume, pp. 71–78 (Egger 2026) and 65–69 (Schölkopf 2026).

3 E.g. Hachenberg 2006; Thein 2006.

4 See Appendix on pp. 39f.

5 "Durchwegs konisch gebaut. Fabelhaft weicher und voller Ton" (Kruspe 1930, characterising the "Quart-Posaune", i.e. a tenor-bass trombone with a valve of a fourth. We are grateful to Tim Dowling for mailing us this pricelist).

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- a conical bell throughout, and therefore mostly no tuning slide (period catalogues offer models with and without a tuning slide);
- a large bell, up to 260 mm maximum;
- a very light bell made of 0.35 mm sheets, hammered at the end down to around 0.20 mm;
- a large Saxon garland;
- as few stiff construction parts as possible: an open slide stay and only one bell stay; these stays made out of a tube.

Further typical features are:

- snake ornaments on the bows;
- touch springs inside the slide housing;
- a friction joint.

German trombones were mostly built as altos in E♭, tenors in B♭ and tenor-basses in B♭. The last was an important innovation: it was a large-bore tenor trombone that played bass parts. It was also called the 'Baritonposaune' or 'Quartposaune' and was often equipped with an F-attachment – a solution that was invented by Sattler in Leipzig in 1839. As a consequence, the earlier bass trombones in low G, F or E♭ became obsolete and then disappeared in Germany, as we can see from extant catalogues and instruments.

The research presented here focused on the era of the large-bore Leipzig trombone. The beginning of this era is marked by the Sattler trombones, developed in the 1830s and extant in the form of the well-known three instruments held by the Grassi Museum: alto, tenor and bass, made for the Leipzig churches and dated 1841.[6] Kruspe's narrower bored Weschke model marks the end of this era. It was developed during the 1920s by Kruspe in collaboration with the Berlin solo trombonist Paul Weschke (1867–1940) and was designed for solo playing. It had a ca 11.5 mm cylindrical bore and a ca 225 mm bell, still combined with a large Saxon garland.[7] Later, this model was adopted both for solo trombones and for all trombone parts in the orchestra. The wide-bore 'Penzel' or 'Leipzig' model then fell out of use.

We gathered together many historical trombones of that era for our research project. Sixty-three of them were played and measured. Figure 1 shows the 50 instruments signed by Saxon makers; the remaining 13 were signed by non-Saxon makers. This list begins at the left in ca 1800 and ends on the right in the 1930s. The trombone sizes are given in order of size with the discant at the top, down to the bass trombones at the bottom. The list includes five instruments by Sattler (highlighted here in green), five by Penzel (yellow), ten by Kruspe (blue) and six by Heckel (red). The majority of these instruments had an inner and outer slide that were clearly still original. For the others, some slides were of doubtful origin, some had clearly been changed (some of them chrome-plated) while others were simply missing.

These instruments were all played in either Basel or Leipzig by Ian Bousfield, a trombone professor at the Bern Academy of the Arts HKB; those in Leipzig were also played by Sebastian Krause, solo trombonist in the MDR Symphony Orchestra in Leipzig. The latter group also included the above-mentioned three Sattlers in the Grassi Museum (given in rectangular frames in Fig. 1).[8]

6 Majewski 2010, pp. 7f.

7 For the Weschke model, see Remmert 2010, pp. 67f.; and Vereecke/Krause 2015.

8 We are grateful to Ian Bousfield for this inspiring journey to the trombone, to Sebastian Krause for all his help and expertise, to the members of the Verein für mitteldeutsche Posaunengeschichte e.V. for bringing their instruments for measuring, and to Josef Focht and Thea Pawula of the Grassi Museum in Leipzig for hospitality and support.

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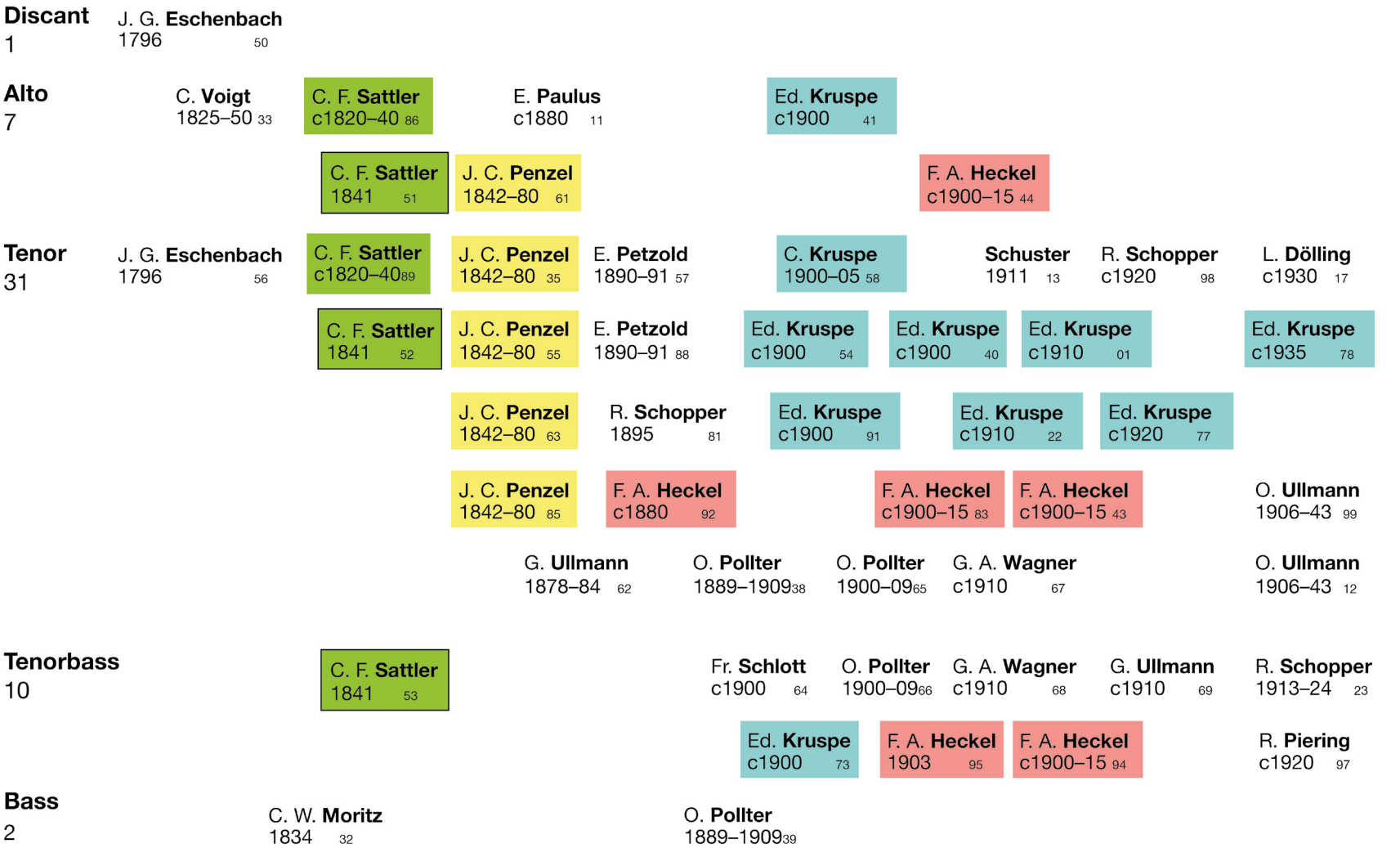

Fig. 1 The 50 trombones from Saxony involved in this project, listed in chronological order from left to right (the small figure indicates the project number; see Appendix, pp. 39f.).

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Historical background

We have to be aware that the above makers manufactured all types of brass instruments. With the exception of Johann Christoph Penzel, the trombone was for most of them actually a side product. Christian Friedrich Sattler's focus was on technical innovation, Eduard Kruspe's on horns and Heckel's on trumpets. Figure 2 shows the only 4 trombone models (each available in three bore variants) found in a Kruspe catalogue of the 1930s. They formed a minority group alongside 13 models of horn, 2 Wagner tubas, 7 trumpets, alto horns, tenor horns and baritone horns, plus 7 models of tuba.

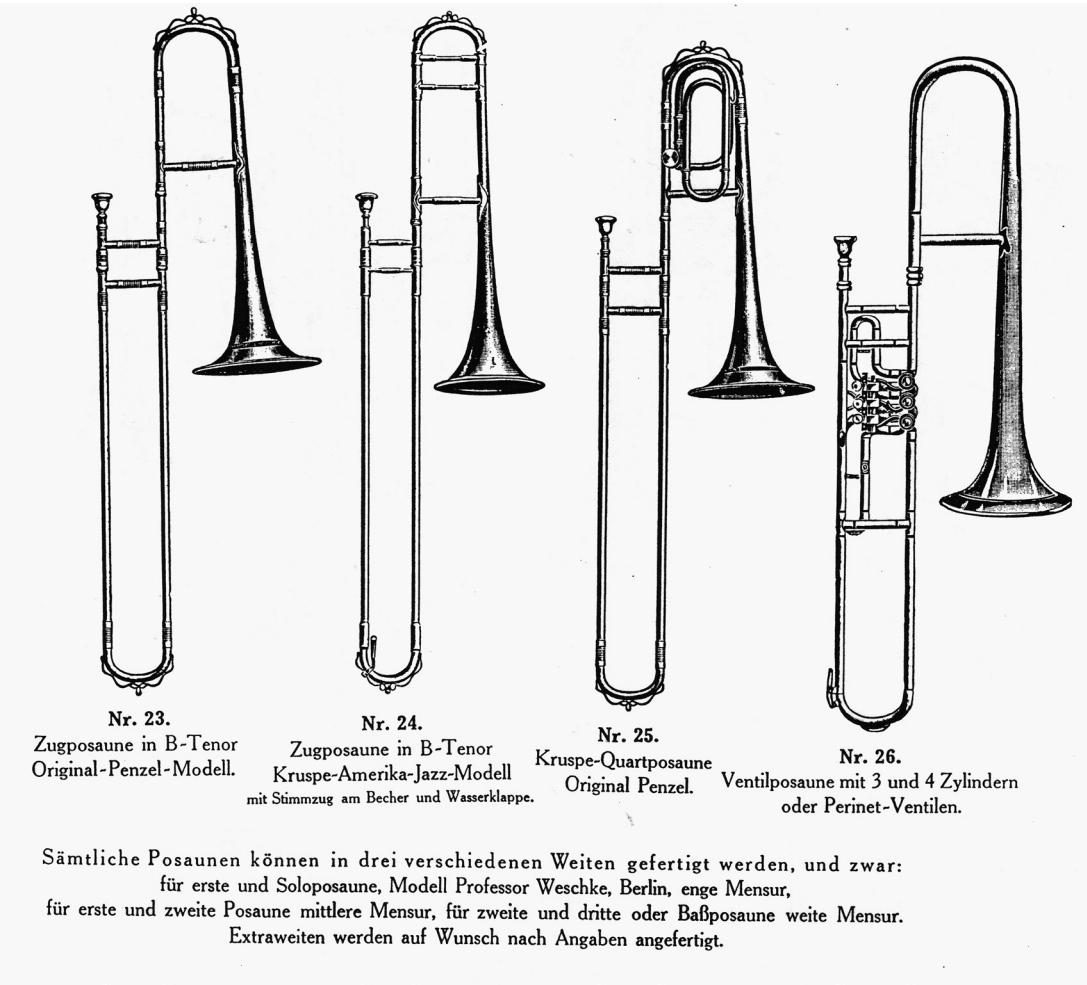

Fig. 2 Trombones in the catalogue of Eduard Kruspe, published in the 1930s (published in *Larigot* 1996, p. 24).

We also have to be aware that in the region of Leipzig and Markneukirchen, the era of the large-bore trombone was also the era of a divided labour economy. Small independent workshops manufactured mouthpieces, bells, valves and all manner of other parts, or offered engraving services. Figures 3–6 show excerpts from the 1912 catalogue of the maker Dölling in Markneukirchen. Dölling defines himself as a 'bell-maker' and offers bells for alto, tenor, tenor-bass and bass trombones with a variety of garlands. But he also offers all manner of other instrument parts, such as slides and snake ornaments. It seems astonishing that he did not manufacture complete instruments. At the close of his catalogue, he prints testimonials. These include one by Eduard Kruspe (E.K. at Erfurt, dated 17 March 1910) saying that the bells delivered had satisfied his requirements and that Dölling can count on further orders from him.

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Firma Ernst Dölling, Schallstück-Fabrik, Markneukirchen

Schallstücke (Fortsetzung).

Nr.		mit franz. Rand	mit Mainz. Neusilber- Drahtrand ed angelöteten Neus.-Kranz	mit eingel. Drahtrand engl. Rand
		Mk.	Mk.	Mk.
	Für Posaunen			
53	F/Es Altposaune, Ventil oder Zug . . .	3,60	4,13	4,28
57	C/B Tenorposaune, gew., Ventil od. Zug	5,55	6,30	6,45
57	C/B Tenorposaune, m. 6½ u. 8½ cm breiten Neusilber-Kranz	—	6,75	
57	C/B Tenorposaune, mit Kronen (Leipziger) 50 Pfg. mehr			
58	C/B Tenorposaune, weit	6,—	6,75	6,90
91	C/B Baßposaune, weit	6,38	7,13	7,28
92	F/Es Baßposaune, (Quartposaune) ganz weit	6,75	7,50	7,65

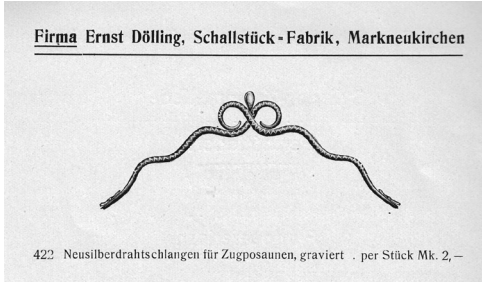
I. Zugrohre

1 Satz Tenorposaunen-Züge mit Neusilber-Anschuh.

von Messing		von Goldmessing		von Neusilber	
gewöhnlich	M. 4.35	gewöhnlich	M. 6.84	gewöhnlich	M. 6.84
konisch Leipz.	M. 4.80	konisch Leipz.	M. 7.14	konisch Leipz.	M. 7.14

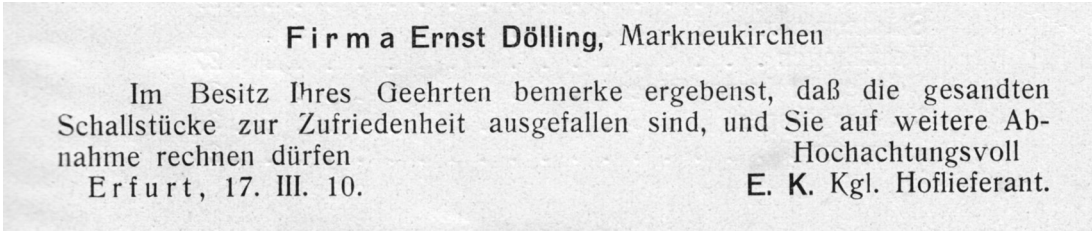
Zugrohre in Weiten 1 bis 15

	in Messing	Goldmessing	Neusilber
70 bis 80 cm lang	per Ko. Mk. 5.40	Mk. 8.25	Mk. 9.75
Eingießrohre (gelötete)	„ „ „ 5.40	„ 8.25	„ 9.05
Eingießrohre **(ohne Naht)**	„ „ „ 6.—	„ 8.40	„ 12.—
Querstegrohre **ohne Naht**	„ „ „ 6.75	„ —	„ 18.—



Firma Ernst Dölling, Schallstück-Fabrik, Markneukirchen

422 Neusilberdrahtschlangen für Zugposaunen, graviert . per Stück Mk. 2,—



Firma Ernst Dölling, Markneukirchen

Im Besitz Ihres Geehrten bemerke ergebenst, daß die gesandten Schallstücke zur Zufriedenheit ausgefallen sind, und Sie auf weitere Abnahme rechnen dürfen

Hochachtungsvoll

Erfurt, 17. III. 10.

E. K. Kgl. Hoflieferant.

Figs. 3–6 Catalogue of 1912 by the bell-maker Ernst Dölling, Markneukirchen: bells (p. 18), slides (p. 26), snake ornaments (p. 40) and a testimonial by Kruspe (p. 45).[9]

Emil Körner in Markneukirchen is known to have made bells for Heckel. Figures 7 and 8 show his mandrill number 124. According to his catalogue from the 1920s, this is the mandrill for his baritone trombone with a bell diameter of 24 cm, and it is offered for the price of 10 Reichsmarks (Fig. 9).[10] Further parts were offered by other Markneukirchen makers; mouthpieces, for example, had been offered by Schmidt since 1842.[11]

In consequence, the instrument maker (the signing company, called 'Zusammensetzer' i.e. 'assembler') had to use what they were given by the part-makers. As we can see from the catalogues, the latter had to offer a great variety of sizes and types of materials (such as red brass as well as yellow brass) in order to meet the demands of the assemblers. An instrument was thus often not designed, developed and produced as a unit by any single company, but by a regional network of independent manufacturers. One could describe this Saxon network as being similar to a large company in which every specialist department was economically independent. This region exported huge numbers of musical instruments. Export companies were called 'Verlag', i.e. distributers. They asked for unsigned instruments so that the customer was unable to trace his instrument back to its real maker. Often, the instruments were signed by the importing dealer.

9 Catalogue held by Musikinstrumentenmuseum Markneukirchen. I am grateful to Enrico Weller for emailing me a copy.

10 I should like to thank Timm Körner, who let me copy this catalogue. He is currently relaunching his grandfather's company in Markneukirchen.

11 See www.schmidt-brass.de/firma-schmidt-mundstuecke-tradition.htm.

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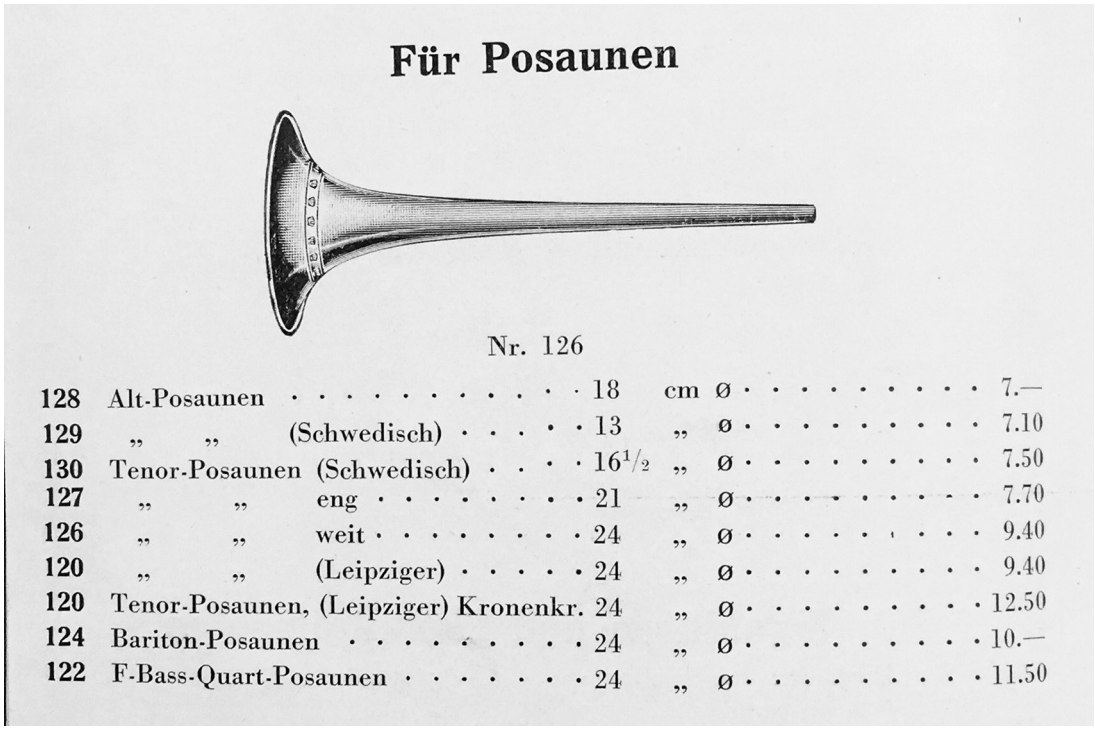

Für Posaunen

Nr. 126

128	Alt-Posaunen	18	cm	Ø	7.—
129	„ „ (Schwedisch)	13	„	Ø	7.10
130	Tenor-Posaunen (Schwedisch)	16½	„	Ø	7.50
127	„ „ eng	21	„	Ø	7.70
126	„ „ weit	24	„	Ø	9.40
120	„ „ (Leipziger)	24	„	Ø	9.40
120	Tenor-Posaunen, (Leipziger) Kronenkr.	24	„	Ø	12.50
124	Bariton-Posaunen	24	„	Ø	10.—
122	F-Bass-Quart-Posaunen	24	„	Ø	11.50

Figs. 7–9 Bell; mandrill 124, marked on the top on the screw; and the catalogue of Emil Körner, Markneukirchen (Körner 1920, p. 4). In the catalogue, bell 124 is listed second last.

In our research project, we furthermore had to bear in mind that the period of the large-bore German trombone was also the period of the valve trombone. Trombonists were just as eager as their trumpet-playing and horn-playing colleagues to get the latest technical devices and options. For a certain time, most orchestras and wind bands had either valve trombones only, or a combination of valve and slide trombones. It was only towards the end of the nineteenth century that symphony orchestras went back to having a trombone section comprising only

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slide trombones. Wind bands kept both types in use together for a longer period (and they accounted for at least 80% of market demand).[12]

Finally, organological research must always consider that studying interfaces is of prime importance. In brass instruments, that means the mouthpieces. Our project first focussed on the instruments and used the same mouthpieces throughout. Later on, we compared mouthpieces using the same instrument. Thanks to Sebastian Krause and the museums, we were able to collect signed, original, period trombone mouthpieces in several sizes and incorporated them when Egger was developing his replicas. Most throats of these mouthpieces were rounded, not etched, as had previously been common. This round throat was developed for Červený in the 1860s by Schmidt in Höchstädt near Markneukirchen.[13]

Alloy

The chemical composition of the alloy for each part of the trombones was analysed by Martin Tuchschmid using X-ray fluorescence spectrometry. Figures 10 and 11 show the results for the 1841 Sattler tenor trombone. While a standard brass for instruments today is the alloy CuZn28 comprising 72% copper and 28% zinc (without any tin or lead), the brass sheets used for this instrument contained 71% copper, 27% zinc, over 1% tin and a little lead. This instrument is a very rare case in that most of the parts are made of the same alloy, even including the garland and the inner slide that are normally made of other materials. One exception on this instrument is the slide bow number 6, which was made of a different alloy containing 66% copper and 33% zinc. We may thus assume that the original bow was damaged and replaced during the lifetime of the trombone. In general, we have to be aware that slides or parts of slides in historical trombones are rarely original because they suffer wear and tear and often get replaced.

Figures 12–13 show a typical example of the alloys used in German trombones. This Kruspe trombone uses nickel-silver (or 'German silver') for the garland, ferrules and stockings. Nickel-silver is brass hardened with the addition of ca 10% nickel. This material, with its silver-like sheen, is much harder to manufacture than normal brass. This is why it was used for instrument parts that were simple in their geometry, but not for bells or bows.

The bell and all the tubes of this instrument are made of brass with a high level of copper (roughly 85%). This alloy is called red brass (or tombac; 'Goldmessing' in German) and was often used in that period by the makers in the Markneukirchen area and Leipzig.

A price list of 1930 by Kruspe in Erfurt illustrates this (Fig. 14). Kruspe here offers a "Modell Penzel" tenor trombone made of normal brass with special prices for tuning slides and for extra features made of nickel silver, such as a garland, inner slide and water key. The most expensive version of this model is in red brass with nickel-silver garniture and water key, with two extra features at 10 Reichsmarks each: a nickel-silver garland and a tuning slide. Our analyses of the alloy suggest that our instrument in Figure 13 is this version of Kruspe's 'Penzel' model that cost 150 Reichsmarks, plus 10 marks extra for the garland with crowns stamped, and 10 marks extra for a tuning slide in the bell bow. Piering in Adorf near Markneukirchen was also offering bells of normal and red brass, and even whole instruments made of nickel-silver.[14]

12 We here rely on Weller 2024. Weller gives quantities for all types of trombones and many details of their production.

13 Oral information from Mr Schmidt, the owner of the company today.

14 A bell of nickel-silver is very hard to manufacture. During our project, we found no bells made of this material.

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Blechblasinstrumente Posaunen Deutschland 19./20. Jhdt.	**Energiedispersive Röntgenfluoreszenzspektrometrie (ED-XRF) - Analysenprotokoll** Messgerät: NITON XL2 Messmodus: ALLOYS Messzeit / Filter: 30 sec / MAIN Leipzig, 12.-14. April 2016; Dr. M. Tuchschmid Empa-SOP: 03'850									
Tenorposaune / Sattler	**Cu**	**Zn**	**Pb**	**Sn**	**Sb**	**Ni**	**Co**	**Fe**	**Mn**	**As**
Nr. 52	%	%	%	%	%	%	%	%	%	%
	[Angaben in Massen-%: Mittelwerte Doppelbestimmung ± Standardabweichung]									
Pos. 1	**71.3**	**26.7**	0.62	**1.3**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Kranz	0.3	0.2	0.06	0.1						
Pos. 2	**71.1**	**27.0**	0.63	**1.3**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Schall	0.4	0.3	0.06	0.1						
Pos. 3	**70.3**	**27.8**	0.52	**1.2**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Bogen	0.3	0.2	0.05	0.1						
Pos. 4	**71.1**	**27.0**	0.60	**1.2**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Zwinge	0.3	0.2	0.06	0.1						
Pos. 5	**70.4**	**27.8**	0.52	**1.2**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Steg	0.3	0.2	0.05	0.1						
Pos. 6	**66.5**	**33.1**	0.28	n.n.	n.n.	0.07	n.n.	n.n.	n.n.	n.n.
Zugbogen	0.3	0.2	0.04			0.02				
Pos. 7	**70.8**	**27.2**	0.58	**1.3**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Aussenzug	0.3	0.2	0.06	0.1						
Pos. 8	**71.0**	**27.2**	0.50	**1.2**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Innenzug	0.3	0.2	0.05	0.1						
Pos. 9	**71.7**	**27.7**	0.45	n.n.	n.n.	0.16	n.n.	n.n.	n.n.	n.n.
Stiefel	0.6	0.6	0.05			0.03				

[n.n. = nicht nachweisbar (<Bestimmungsgrenze) / Bestimmungsgrenzen = 0.05 - 0.1 Massen-% (matrix- und elementabhängig)]

Figs. 10–11 Alloys of the Sattler tenor trombone, dated 1841; n.n. = not detectable.

It is noteworthy that the bell of the Kruspe tenor trombone contains 1% nickel, as does the bell stay (see Fig. 12). This might be an indication of its provenance.[15] The fact that the other parts of the instrument do not have this chemical composition suggests that they were made by another maker, and the bell by a bell-maker. In our case, this might have been Dölling in Markneukirchen, who was one of Kruspe's suppliers, as we saw above. Such small amounts of nickel in instrument parts, mostly bells, were also found in the trombones of other makers. This again illustrates the degree of collaboration of specialist companies in Saxony at that time.

Our analyses of alloy measurements reveal that a great variety of brass alloys was used for all parts of these trombones. We undertook all possible analyses of these figures. The statistic for copper versus nickel in the alloys is of particular interest (Fig. 15). We restricted our analyses to bells and bell bows, leaving out the slide and the other parts of the instrument's construction for which we cannot know if they are original or not. On the x axis we can see two clearly distinct groups here: yellow brass with around 70% copper, and red brass with around 85–90% copper. The latter was not only used by Kruspe and Piering, as seen above, but also by the other makers. For Heckel (yellow squares), red brass seems to have been standard. Kruspe used red brass as well as yellow brass. This corresponds to his price list as given above. Sattler (red triangles) did not use red brass, while his successor Penzel (green circles) used red brass for one instrument but not for the others.

15 See Jean-Marie Welter's article on pp. 43–64 of this volume (Welter 2026).

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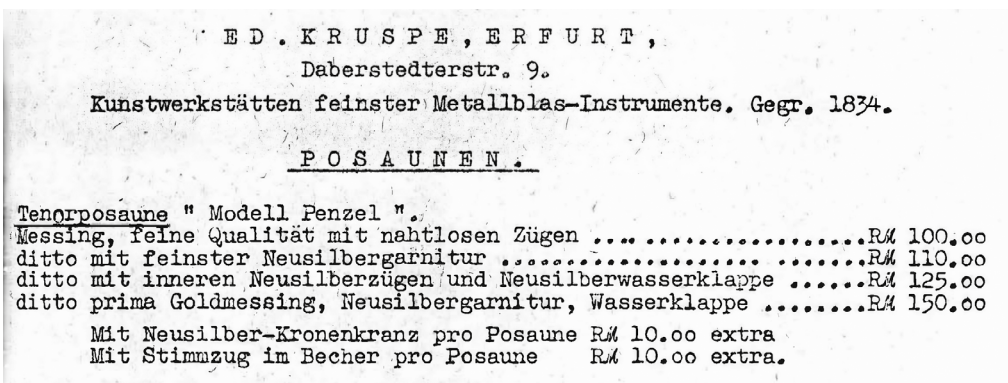
Tenorposaune / Kruspe Nr. 01 / Egger	Cu %	Zn %	Pb %	Sn %	Sb %	Ni %	Co %	Fe %	Mn %	As %
	[Angaben in Massen-%: Mittelwerte Doppelbestimmung ± Standardabweichung]									
Pos. 1	**66.3**	**22.1**	0.24	0.15	n.n.	**10.5**	0.12	0.43	n.n.	n.n.
Kranz	0.4	0.2	0.04	0.02		0.1	0.02	0.04		
Pos. 2	**86.6**	**11.9**	0.12	0.09	n.n.	**1.2**	n.n.	0.05	n.n.	n.n.
Schall	0.2	0.2	0.03	0.02		0.1		0.02		
Pos. 3	**83.2**	**16.2**	0.11	0.09	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Bogen	0.3	0.2	0.03	0.02						
Pos. 4	**62.4**	**24.2**	0.16	n.n.	n.n.	**12.8**	n.n.	0.18	0.10	n.n.
Zwinge	0.4	0.2	0.03			0.1		0.03	0.03	
Pos. 5	**86.1**	**12.2**	0.15	0.06	n.n.	**1.3**	n.n.	0.05	n.n.	n.n.
Steg	0.2	0.2	0.03	0.02		0.1		0.02		
Pos. 6	**83.1**	**16.3**	0.11	0.11	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Zugbogen	0.2	0.2	0.03	0.02						
Pos. 7	**83.4**	**16.3**	0.09	0.15	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Aussenzug	0.3	0.2	0.03	0.02						
Pos. 8	**83.3**	**16.6**	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Innenzug	0.3	0.2								
Pos. 9	**62.6**	**23.9**	0.14	n.n.	n.n.	**13.0**	n.n.	0.19	0.12	n.n.
Stiefel	0.3	0.3	0.03			0.3		0.03	0.03	

[n.n. = nicht nachweisbar (<Bestimmungsgrenze) / Bestimmungsgrenzen = 0.05 - 0.1 Massen-% (matrix- und elementabhängig)]

Figs. 12–13 The alloys of a Kruspe tenor trombone, early twentieth century.

On the y axis in Figure 15, we see that ca 1% nickel is found in some parts of these instruments (this is not to be confused with nickel-silver, which is comprised of 10% nickel and was used for garlands and other parts). It is notable that this nickel is present only in red brass. We have been unable to find any source that mentions this material, and therefore conclude that it was not consciously used by makers such as the bell-maker Dölling. This leads us to the hypothesis that the nickel entered the alloy in the factories of the brass manufacturers who delivered metal sheets to the instrument makers. Based on these results, Egger decided to use red brass for the replicas.[16]



E D . K R U S P E , E R F U R T ,
Daberstedterstr. 9.
Kunstwerkstätten feinster Metallblas-Instrumente. Gegr. 1834.

P O S A U N E N .

Tenorposaune " Modell Penzel ".
Messing, feine Qualität mit nahtlosen Zügen .....RM 100.00
ditto mit feinster Neusilbergarnitur .....RM 110.00
ditto mit inneren Neusilberzügen und Neusilberwasserklappe .....RM 125.00
ditto prima Goldmessing, Neusilbergarnitur, Wasserklappe .....RM 150.00
Mit Neusilber-Kronenkranz pro Posaune RM 10.00 extra
Mit Stimmzug im Becher pro Posaune RM 10.00 extra.

Fig. 14 Price list of Eduard Kruspe (1930).

16 See the article by Alex Schölkopf on pp. 65–69 of this volume (Schölkopf 2026).

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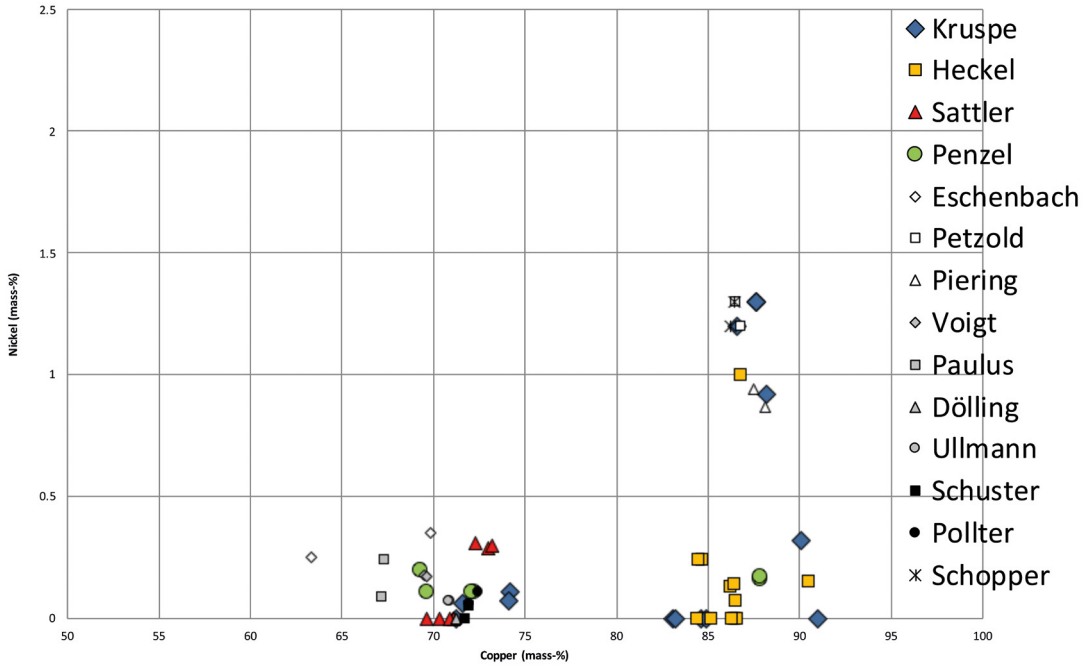

Fig. 15 Statistic copper versus nickel for bells and bell bows of 31 Saxon trombones.

Wall thickness

Adrian v. Steiger has made several thousand measurements of all types and parts of historical brass instruments. To this end, he employs an ultrasound device whose small sensor can measure wall thickness at almost any point of an instrument. This provides a basis for estimating the thickness of the original sheet metal of each part of an instrument. As a general rule, the thickest spot of an instrument part is equal to the original sheet's thickness, as is shown below. These measurements also lead to a better understanding of the manufacturing techniques utilised.[17]

The ultrasound device is accurate to one micrometre. This can be illustrated by measuring new brass sheets. The roll in Figure 16 is 0.4 millimetres in thickness according to its manufacturer, and our measurement confirms it with a tolerance of 1 thousandth after making 14 measurements of it. ".400" here means 0.400 millimetres. In the following, the measurements are rounded off to the next hundredth millimetre.

With the help of such measurements, we can observe the behaviour of brass during the hand-hammering manufacturing process. Figure 17 shows four bells at Egger's workshop before the shaping process. They are made of 0.4 mm sheet brass. At most points, this thickness is unchanged, ranging from 0.40 to 0.39.

These points were marked so that we would be able to locate them again, and were then measured ten more times, once after each single manufacturing step: being hammered three times, being centred four times, and after being spun on the lathe, filed and polished. Figures 18–20 show that the thickness was reduced at most of these points during these processes, as we would expect (these reductions are marked in yellow; big differences compared to previous thickness are marked in green). At some points, however, the brass became thicker during certain manufacturing steps (these are marked in pink, with major increases marked in red).

17 For the wall thicknesses of French instruments, see Steiger 2016.

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Fig. 16 A modern roll of brass at Egger's workshop. The 14 measurements show that the 0.4 mm thickness is within a tolerance of 1/1000 mm.

This allows us to observe how the material behaves almost like a liquid. At the end, after polishing, the thickest spot was equal to the initial thickness of the sheet, namely 0.40 mm.

What can we learn from this for manufacturing replicas? Copying the wall thickness at every point is impossible and cannot be our goal. But we can derive key measurements from the historical originals for both the thickness of the sheet metal and for the resulting wall thickness. On this basis, we can use historical manufacturing techniques in a way that can reproduce those key thicknesses in the replicas.

Three typical historical trombones may illustrate this. The bell of the trombone by Johann Christoph Penzel, ca 1860 (Fig. 21), was made out of a thin sheet. The thickest measurement here is 0.31 mm. The thinnest spot on the bell is 0.17 mm, below the garland. The bell is also thin at the bell bow, 0.30 mm maximum. These parts might therefore be made from a sheet of ca 0.30 mm. In contrast, the outer slide is made of thicker material, its thickest measurement being 0.38 mm.

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Figs. 17–20 Wall thicknesses of the same four bells after opening (top left), after being hammered three times (top right), after being centred four times (bottom left) and after being spun on the lathe, filed and polished (bottom right).

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All the bells that we measured from the Heckel company are extremely thin – such as the ca 1903 tenor-bass trombone by Friedrich Alwin Heckel (Fig. 22). The thickest spot on this bell is 0.26 mm, so the original sheet might have been thinner than 0.3 mm. At the bell, the brass has been hammered down to 0.20 mm. According to all our measurements, this 0.20 mm is typical for the bells of German trombones. As seen above, they might have been manufactured by the specialised bell-maker Körner (see Fig. 9, in contrast to the "Bariton-Posaunen" in this catalogue, the bell of the trombone in Fig. 22 measures only 23 cm in diameter). In this Heckel trombone, the outer slide is made of thin material while the inner slide is thicker, being made of ca 0.45 mm brass. In Rainer Egger's interpretation of these facts, the typical thin bell of German trombones had to be acoustically balanced by thicker material in the slide. In the examples shown, the Penzel (Fig. 21) has a heavy outer slide (which is uncomfortable for the player) while the Heckel has a heavy inner slide with the same acoustical effect.

The bell of the Kruspe (Fig. 23) seems to have been made out of a sheet ca 0.3 mm in thickness; 0.30 mm is the thickest spot. It has been hammered down to ca 0.20 mm at the bell. The two tubes of the inner slide differ in size. As we can never know which parts of a slide are original and which ones might have been replaced, we can offer no interpretation of its weight balance.

Figs. 21–23 Three typical trombones by J. C. Penzel (left, private collection Sebastian Krause), F. A. Heckel (middle, private collection Jürgen Kamjunke) and Ed. Kruspe (right, private collection Rainer Egger); in green: inner slide measurements (stock. = stockings), in blue: garland, in orange: bell below the garland.

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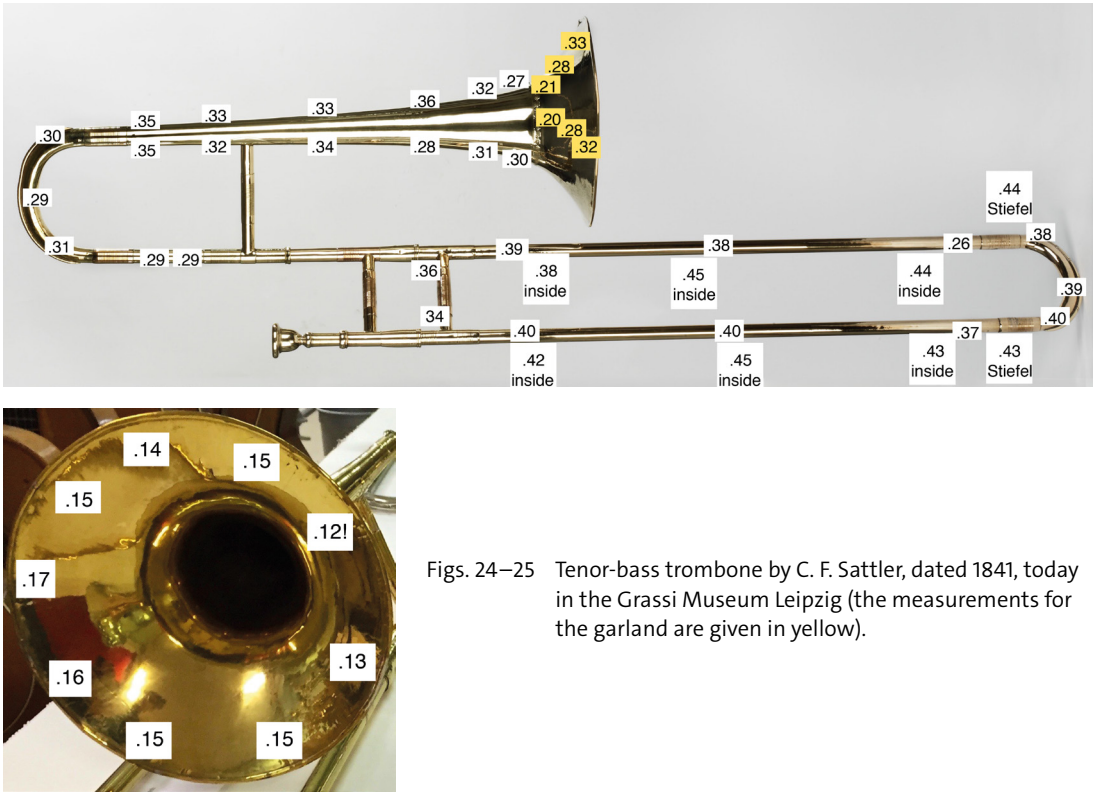
The above-mentioned tenor-bass trombone by Christian Friedrich Sattler, dated 1841 and part of a set of three trombones, is an interesting instrument in many aspects (Fig. 24). The thickest measurement for the bell is 0.36 mm, meaning that it was made from a sheet of ca 0.35 mm. But at its end, underneath the garland, this bell is extremely thin. The nine measurements around the bell range from 0.17 to 0.12 mm (Fig. 25). This last measurement is the thinnest point that we have ever found on a brass instrument and is the same thickness as a single sheet of paper.

In our opinion, this special bell was made when Sattler took the usual pattern for his tenor trombone, but worked it until it was bigger in order to arrive at what we today call a tenor-bass trombone, or simply a bass trombone in B♭. The material had to become thinner to attain the intended bigger bell. This instrument is a very early example of a trombone made for playing bass parts, but with the length of the tenor B♭ trombone. It was the same Sattler who in 1839 presented an F-attachment for such instruments. No such valve is known to have survived, and he did not make use of it in this special case, which was intended for use in church.



Figs. 24–25 Tenor-bass trombone by C. F. Sattler, dated 1841, today in the Grassi Museum Leipzig (the measurements for the garland are given in yellow).

In conclusion, we can decide the thickness of the metal sheet for manufacturing a replica based on such analyses. In the case of the German trombones, this leads us to make bells out of brass sheets substantially thinner than the usual 0.4 mm; they have to be mostly 0.35 mm, for Heckel replicas even 0.30 mm.

Just as musicians need to be informed about historical practices when they interpret music of earlier periods, so does an instrument maker of historical brass instruments need to be informed about the materials and manufacturing techniques of the period in question. This begins with his choice of brass sheets, their alloy and thickness, as discussed in the present paper. He must then proceed to study the geometries and technical features of selected historical instruments and conclude with playing tests in order to achieve a better understanding of how each parameter influences the manufacturing process. Only then will fine instruments find their way into the hands of fine artists.

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Appendix

List of the trombones chosen for the project

No.	Project inventory number (certain figures omitted)
Maker	As given on the instrument
p.c.	Private collection
CH.BE.km	Klingendes Museum Bern, formerly the Karl Burri collection
CH.BE.hkb	Bern Academy of the Arts HKB
CH.B.hm	Musikmuseum Basel
DE.LE.u	Grassimuseum Leipzig

No.	Trombone	Maker	Date	Today at
1	Tenor	Ed. Kruspe, Erfurt	early 20th c.	p.c. Egger
11	Alto	E. L. Paulus, Berlin	1866–1899	CH.BE.km 83
12	Tenor	Oskar Ullmann, Leipzig	1906–1943	CH.BE.km 87
13	Tenor	Schuster & Cie, Markneukirchen	dated 1911	CH.BE.km 307
15	Tenor	Schediwy, Ludwigsburg	1901–1944	CH.BE.km 84
16	Tenor-bass	Max Reiner, Thun	first half 20th c.	CH.BE.km 85
17	Tenor	Louis Dölling jr., Markneukirchen	1917–1950	CH.BE.km 1123
18	Tenor-bass	Otto Hofmann, Bern	1914–1955	CH.BE.km 86
21	Tenor	J. Riedl, Bremen	unknown	CH.BE.hkb 21431
22	Tenor	Ed. Kruspe, Erfurt	first half 20th c.	CH.BE.hkb 21432
23	Tenor-bass	R. Schopper, Leipzig	1913–1924	CH.BE.hkb 21440
31	Tenor	Michael Saurle, München	dated 1834	CH.B.hm 1980.2139
32	Bass	C. W. Moritz, Berlin	dated 1841	CH.B.hm 1980.2340
33	Alto	C. Voigt, Neukirchen	2nd quarter 19th c.	CH.B.hm 1980.2023
35	Tenor	J. C. Penzel, Leipzig	3rd quarter 19th c.	CH.B.hm 1980.2124
36	Tenor	A. F. Kochendörfer, Stuttgart	later than 1867	CH.B.hm 1980.2700
37	Tenor	Klemm [French instrument?]	around 1900	CH.B.hm 1980.2106
38	Tenor	O. Pollter & Co, Leipzig	ca 1887–1909	CH.B.hm 1980.2527
39	Bass	Pollter & Co, Leipzig	ca 1887–1909	CH.B.hm 1944.2743
40	Tenor	Ed. Kruspe, Erfurt	early 20th c.	CH.B.hm 2009.726
41	Alto	Kruspe, Erfurt	early 20th c.	CH.B.hm 2009.725
42	Tenor	Norbert Wahlich, Zürich	early 20th c.	CH.B.hm 2009.724
43	Tenor	F. A. Heckel, Dresden	early 20th c.	CH.B.hm 2009.723
44	Alto	F. A. Heckel, Dresden	early 20th c.	CH.B.hm 2009.722
45	Tenor	Otto Hofmann, Bern	1927–1955	CH.B.hm 1980.2587
46	Alto	Georg Müller, Mannheim	mid-19th c.	CH.B.hm 2004.299
47	Tenor	Hug / [Anonym German]	early 20th c.	CH.B.hm 2011.684
50	Discant	J. G. Eschenbach, Neukirchen	dated 1796	DE.LE.u 1880

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No.	Trombone	Maker	Date	Today at
51	Alto	C. F. Sattler, Leipzig	dated 1841	DE.LE.u 4137
52	Tenor	C. F. Sattler, Leipzig	dated 1841	DE.LE.u 4138
53	Tenor-bass	C. F. Sattler, Leipzig	dated 1841	DE.LE.u 4139
54	Tenor	Ed. Kruspe, Erfurt	1875–1900	DE.LE.u 4892
55	Tenor	J. C. Penzel, Leipzig	ca 1855	DE.LE.u 3303
56	Tenor	J. G. Eschenbach, Neukirchen	dated 1796	DE.LE.u 1899
57	Tenor	Ernst Petzold, Leipzig	1890–1891	p.c. Brix
58	Tenor	Carl Kruspe, Leipzig	1900–1905	p.c. Brix
61	Alto	J. C. Penzel, Leipzig	ca 1850	p.c. Hett 0301-1
62	Tenor	Gustav Ullmann, Leipzig	1878–1884	p.c. Hett 1510-5
63	Tenor	J. C. Penzel, Leipzig	ca 1860	p.c. Hett 0301-2
64	Tenor	Fr. Schlott, Leipzig-Gohlis	end 19th c.	p.c. Hett 1501-5
65	Tenor	O. Pollter & Co, Leipzig	after 1900	p.c. Kamjunke
66	Tenor-bass	O. Pollter & Co, Leipzig	after 1900	p.c. Kamjunke
67	Tenor	Gustav A. Wagner, Dresden	ca 1910	p.c. Kamjunke
68	Tenor-bass	Gustav A. Wagner, Dresden	ca 1910	p.c. Kamjunke
69	Tenor-bass	Oscar Ullmann, Leipzig	ca 1910	p.c. Hett
73	Tenor(-bass)	Ed. Kruspe, Erfurt	early 20th c.	p.c. Majewski
77	Tenor	Ed. Kruspe, Erfurt	early 20th c.	p.c. Majewski
78	Tenor	Ed. Kruspe, Erfurt	ca 1935	p.c. Majewski
81	Tenor	R. Schopper, Leipzig	ca 1895	p.c. Krause
83	Tenor(-bass)	F. A. Heckel, Dresden	after 1919	p.c. Krause
85	Tenor	J. C. Penzel, Leipzig	ca 1860	p.c. Krause
86	Alto	C. F. Sattler, Leipzig	first half 19th c.	p.c. Krause
88	Tenor	Ernst Petzold, Leipzig	1890–1891	p.c. Krause
89	Tenor	C. F. Sattler, Leipzig	first half 19th c.	p.c. Krause
90	Alto	Kruspe, Erfurt	ca 1950	p.c. Krause
91	Tenor	Firma Ed. Kruspe, Erfurt	ca 1905	p.c. Kamjunke
92	Tenor	F. A. Heckel, Dresden	ca 1880	p.c. Kamjunke
94	Tenor-bass	F. A. Heckel, Dresden	ca 1910	p.c. Kamjunke
95	Tenor-bass	F. A. Heckel, Dresden	dated 1903	p.c. Kamjunke
96	Tenor	W. Leonhardt, Erfurt	first half 20th c.	p.c. Kamjunke
97	Tenor-bass	Robert Piering, Adorf	first half 20th c.	p.c. Kamjunke
98	Tenor	R. Schopper, Leipzig	ca 1920	p.c. Kamjunke
99	Tenor	Oscar Ullmann, Leipzig	ca 1920	p.c. Kamjunke

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*As a young instrument maker, **Rainer Egger** experienced first-hand the pioneering era of replicas of historical brass instruments in the workshop of his father, Adolf Egger. Since then, he has been passionate about the constant improvement of brass instruments, especially with regard to richness of sound and the musical functionality of reproductions of historical trumpets, trombones and horns. In order to satisfy the growing, increasingly demanding needs of performers, he is constantly experimenting with different work techniques, scales, materials and wall thicknesses.*

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