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Subjective and instrumental evaluation of noise from a fuel metering pump of a parking heater

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The noises produced by a fuel metering pump of a parking heater are evaluated both subjectively and instrumentally. Relevant parameters are control voltage as well as type and viscosity of the fuel. As expected, the radiated sound pressure level increases with control voltage and viscosity. Subjective evaluations of loudness are performed using the method of magnitude estimation with anchor sound. Two anchor sounds with rather different loudness are used. In addition, psychoacoustic evaluations using category scaling with symbols are performed. Instrumental measurements include determination of A-weighted sound pressure level as well as loudness measurements using DIN 45631/A1. The instrumental loudness measurements are in line with the subjective loudness evaluations. For practical applications is most relevant that when reducing the control voltage of the fuel metering pump by a factor of 1.3 the noise can be reduced by a factor of about 1.7 without compromising the functional capability.

1 INTRODUCTION

Sound quality is one of the important features of modern premium vehicles (e.g. Zeller[1], Genuit[2]). Therefore, over the years, studies of applied psychoacoustics to assess sound quality have gained more and more importance (Fastl[3-5]). Sound quality is clearly linked to expectations of customers and their preferences for specific brands (Blauert and Jekosch[6] Filippou et al.[7]). For the overall sound quality of a vehicle, not only the main components like motor, gearbox, muffler etc. are of importance, but also ancillary components like a parking heater can play an

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important role. As a rule, a parking heater produces only little noise below some 55 dB(A). However, even sounds from its fuel metering pump which are around only 40 dB(A) can lead to complaints of discerning customers of premium or even camping vehicles.

Therefore, the sounds produced by a fuel metering pump of a parking heater were studied in psychoacoustics experiments. Physical and subjective evaluations were performed, and the latter results were correlated with predictions by psychoacoustic metrics like loudness according to DIN 45 631/A1.

2 PHYSICAL MEASUREMENTS

For the measurements, the main parameter studied was the control voltage of the fuel metering pump. It is to be expected that with increasing voltage the noise produced by the pump will increase. In addition, the type of fuel (Diesel vs. Gasoline) and the temperature of the fuel will influence the magnitude and character of the noise.

The recordings of the test sounds were performed by a dummy head (Head Acoustics) seated in the driver's seat of a VW Golf 5. The vehicle was placed in a climate chamber and measurements were taken at 0°C and at -15°C. In order to achieve the desired temperature of the vehicle and the fuel, for the pre-cooling a time span of seven hours was chosen, respectively. In this way, the desired temperature could be ascertained within +/- 1°C.

Figure 1 shows as an example the A-weighted sound pressure level measured with the time constant "fast" at the right ear of the dummy head as a function of the control voltage delivered to the fuel metering pump. The fuel used was Diesel as distributed in winter time. The left panel shows the data at 0°C, the right panel at -15°C.

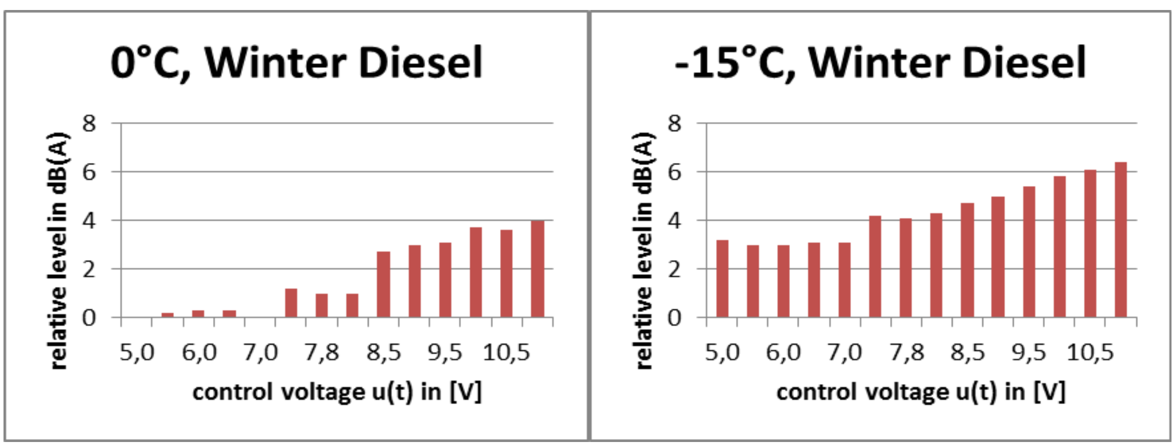

Fig. 1 – Dependence of A-weighted sound pressure level produced by the fuel metering pump as a function of the control voltage. Temperature: 0°C (left) or -15°C (right). Diesel fuel as distributed in winter.

The data displayed in Fig. 1 illustrate that at -15°C the noise produced by the fuel metering pump is by about 2…3 dB higher than at 0°C. This effect seems to be due to the influence of the temperature on the viscosity of the fuel. As a function of control voltage, the sound pressure level produced by the fuel metering pump is very similar for voltages between 5.0 and 7.0 V. At voltages between 9.5 and 11.0 V A-weighted sound pressure levels are reached, which are about 3 dB higher than at low voltages. It is clear that the location of the fuel metering pump, its mounting, the detailed features of the fuel etc. can influence the sound pressure level produced. Nevertheless, the data displayed in Fig.1 can be regarded as typical.

3 PSYCHOACOUSTIC LOUDNESS EVALUATIONS

Sounds for the psychoacoustics experiments were recorded in the acoustic chamber at Webasto in Gilching, Germany at a temperature of 23°C using Diesel as fuel.

3.1 Subjects, sounds, and procedures

27 subjects aged between 17 and 63 years (median 38 years) took part in the experiments. According to their self-report, the subjects had no hearing problems and can be regarded as typical for users of parking heaters. In addition to a larger range of ages, also a broad range of professions was desired including students, trainees, clerks, IT-consultants, R&D engineers, scientists and acoustic consultants. Because of this selection, more than 70 % of the subjects were male.

Two different psychoacoustic procedures were used to assess the loudness of the sounds produced by the fuel metering pump of the parking heater: (a) magnitude estimation with anchor sound, (b) category scaling with anchor sound using symbols.

Sounds were arranged in pairs with 1.5 s sound duration each, separated by intervals of 0.4 s and pauses of 3 s between pairs. With the magnitude estimation, two anchor sounds were used: the anchor 100 for a control voltage of 10.0 V and the anchor 10 for a control voltage of 6.5 V. In each experiment, 60 sound pairs had to be evaluated.

In magnitude estimation, the subjects had to map the perceived loudness to the continuum of numbers as illustrated by the following examples: When the second sound in a pair was only one fifth as loud as the anchor sound 100, the subject had to enter 20 into the keyboard. Likewise, when the second sound in a pair was three times louder than the anchor sound 10, the subject had to enter 30 into the keyboard, and so forth.

With the category scaling the task of the subject was as follows: In each pair, the loudness of the first (anchor) sound is compared to the loudness of the respective second (test) sound. If the loudness of anchor and test sound is the same, the subject should answer with the symbol 0. The symbols +, ++, +++ are used, if the second sound is slightly louder, louder, or much louder as the anchor sound. Correspondingly, the symbols -, --, --- denote that the test sound is slightly softer, softer, or much softer than the anchor sound.

Sounds were presented in a sound attenuating booth using electrodynamic headphones (Beyer DT 48) with free-field equalizer according to Fastl and Zwicker[8].

3.2 Loudness evaluations with anchor sound at 10V control voltage

Results displayed in Fig. 2 illustrate the dependence of loudness evaluations on control voltage obtained with magnitude estimation using the sound produced by the fuel metering pump at a control voltage of 10 V as anchor sound, assigned the number 100. Data are given as medians with inter-quartiles.

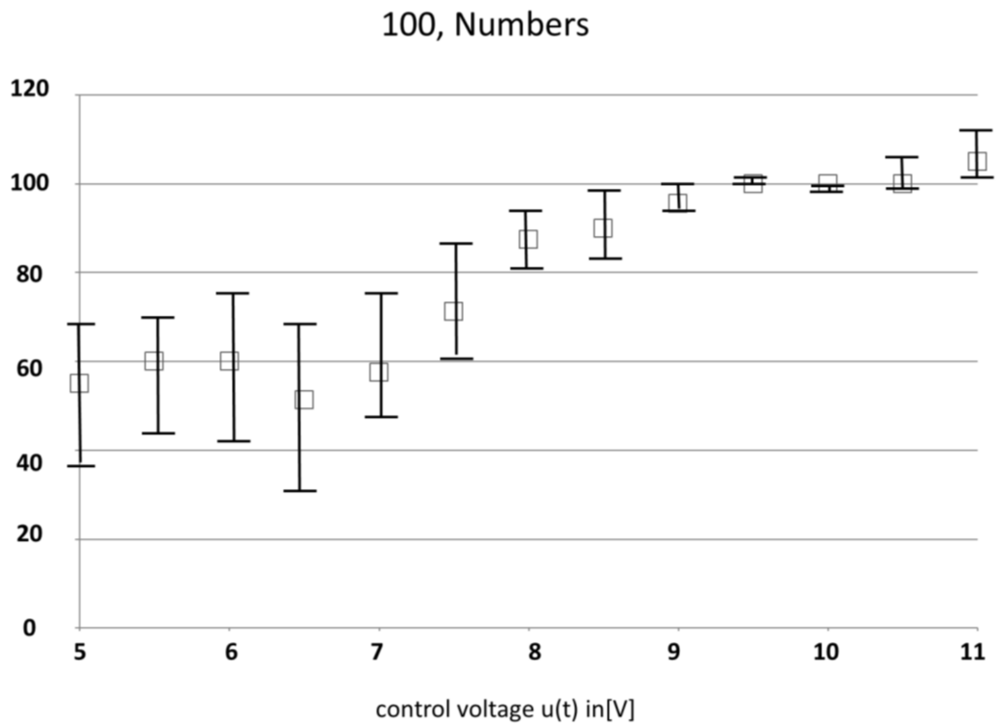

Fig. 2 – Loudness evaluation of the sounds produced by the fuel metering pump of a parking heater as a function of the control voltage. Magnitude estimation using the sound produced for a control voltage of 10 V as anchor sound, assigned the number 100.

The loudness evaluations displayed in Fig. 2 can be grouped in three regions: a first region up to about 7 V with loudness estimates around 50 to 60, a second region between about 7 and 9 V, where loudness increases with control voltage, and a third region for control voltages above 9.5 V with loudness estimates around 100. When regarding the medians (squares), the loudness produced by the fuel metering pump seems to increase by almost a factor of two for the increase in control voltage considered.

When presenting the same sounds, using the category scaling with symbols, the results displayed in Fig. 3 are obtained.

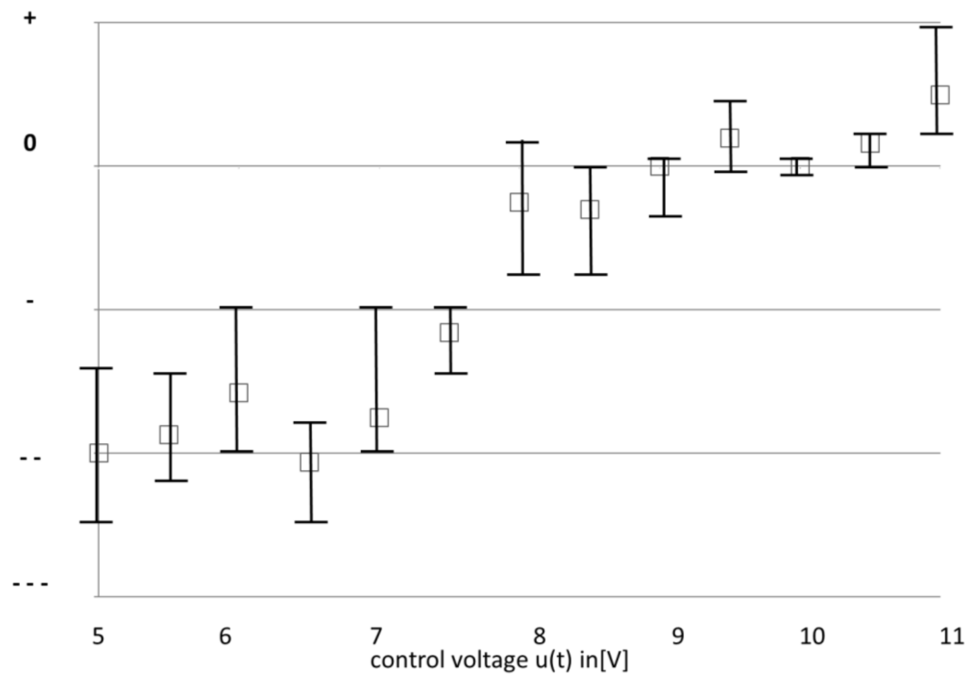

Fig. 3 – Loudness evaluation of the sounds produced by the fuel metering pump of a parking heater as a function of the control voltage. Same sounds as used for Fig. 2, but with category scaling using symbols.

The results illustrated in Fig. 3 clearly show that the subjects faithfully recognized the anchor sound by using the symbol 0, i.e. no difference in loudness between anchor and test sound for a control voltage of 10V. Again, up to about 7 V control voltage, the loudness evaluation is very similar and near the symbol - - which means softer than the anchor sound. Above 9 V the loudness estimates are about the same as indicated by the symbol 0. Between about 7 and 9 V control voltage, the loudness estimates increase from softer (--) via slightly softer (-) to same (0).

3.3 Loudness evaluations with anchor sound at 6.5V control voltage

Since when using the method of magnitude estimation, the results obtained can depend on the anchor sound chosen, it is advisable, to perform experiments with at least two (rather different) anchor sounds. Therefore, two more experiments were performed using the sound produced by the fuel metering pump of the parking heater at a voltage of 6.5V as anchor sound. Thus, the requirements for different anchor sounds were met, since the loudness produced by the fuel metering pump differs substantially for control voltages of 6.5 and 10V, respectively.

The results displayed in Fig. 4 illustrate the dependence of loudness evaluation on control voltage obtained with magnitude estimation using the sound produced by the fuel metering pump at a control voltage of 6.5 V as anchor sound, assigned the number 10

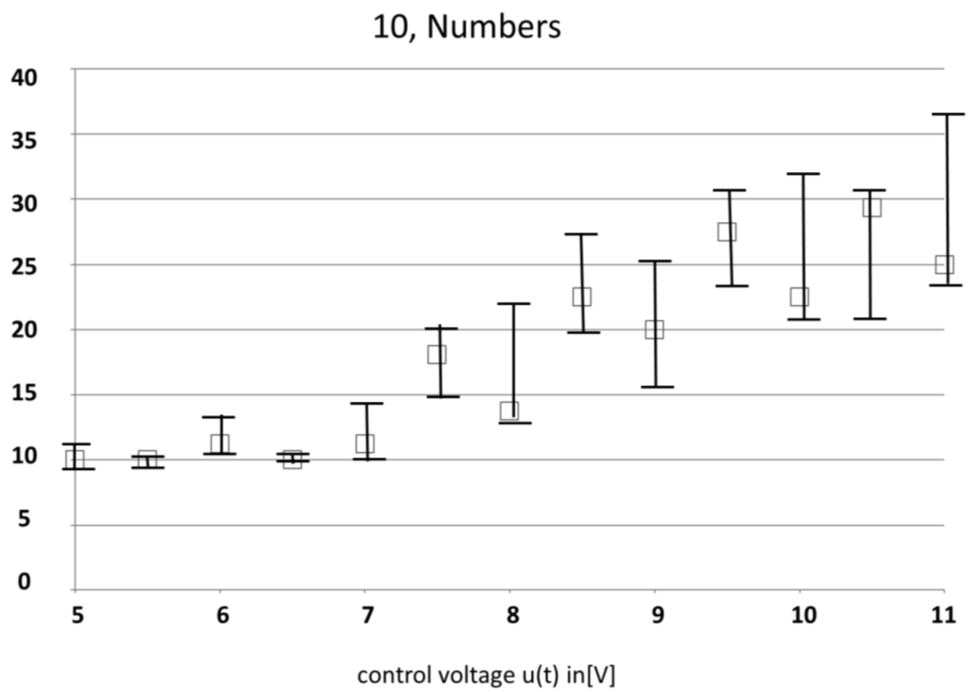

Fig. 4 – Loudness evaluation of the sounds produced by the fuel metering pump of a parking heater as a function of the control voltage. Magnitude estimation using the sound produced at a control voltage of 6.5V as anchor sound, assigned the number 10.

The data plotted in Fig.4 show a similar trend as the data in the two previous figures: Up to about 7V control voltage, the loudness of the fuel metering pump is rather similar and close to the numerical value of the anchor sound 10. Between 7 and 9.5V, the loudness increases with control voltage. Above about 9.5 V the loudness is more or less independent of the control voltage, however, larger inter-quartiles show up. The rather clear division into three sections as seen in Fig.2 is not so obvious in Fig.4. Nevertheless, the dependence of the loudness produced by the fuel metering pump on control voltage seems to be rather similar for different anchor sounds. However, the magnitude of the loudness increase with control voltage seems to depend somewhat on the anchor sound used: As illustrated in Fig.2, for an anchor sound at 10V assigned the number 100, the evaluated loudness increases for voltages between 5 and 11 V from about 55 to about 100, i.e. by about a factor of two. On the other hand, as displayed in Fig. 4, for an anchor sound at 6.5V assigned the number 10, the evaluated loudness increases from 10 to about 25, i.e. by about a factor of 2.5 for an increase in voltage from 5 to 11 V.

When the same sounds as for Fig.4 are presented, but the method of category scaling with symbols is used, the results displayed in Fig. 5 are obtained.

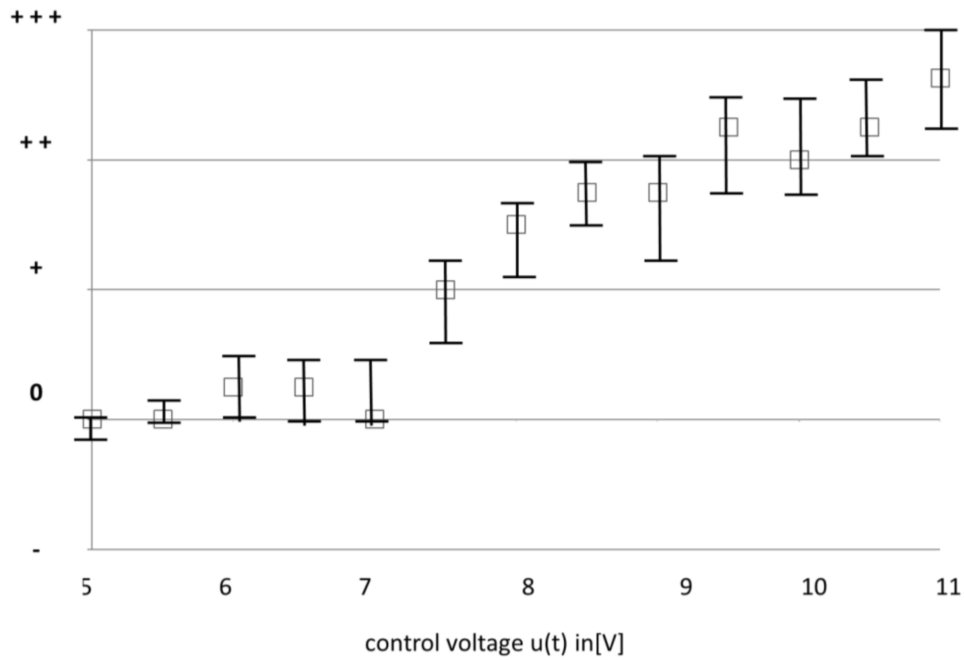

Fig. 5 – Loudness evaluation of the sounds produced by the fuel metering pump of a parking heater as a function of the control voltage. Same sounds as used for Fig. 4, but with category scaling using symbols.

The data illustrated in Fig. 5 again show the familiar pattern: Almost same loudness (0) up to 7 V control voltage, increase of loudness with control voltage from 7 to 9V, and larger loudness (++) for control voltages above 9 V

4 INSTRUMENTAL LOUDNESS EVALUATIONS

The same sounds as used in the psychoacoustic experiments were evaluated instrumentally using the algorithm illustrated in DIN 45631/A1. In Fig. 6 the instrumentally measured loudness (in sone) is plotted as a function of the control voltage applied to the fuel metering pump of a parking heater.

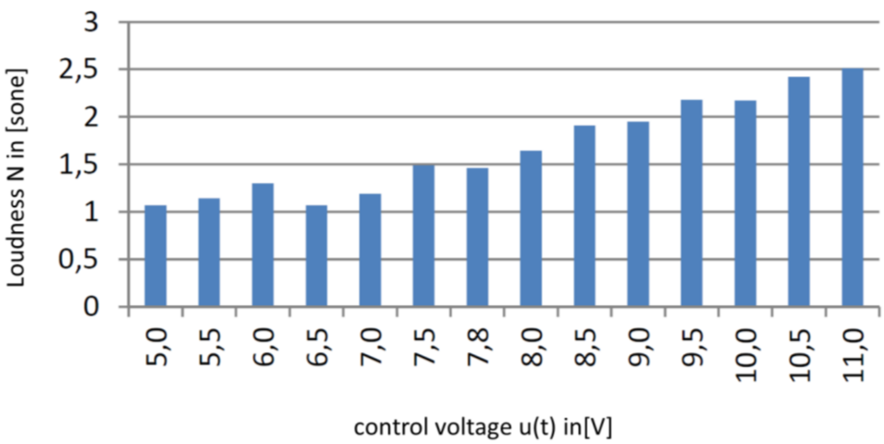

Fig. 6 – Instrumental loudness evaluation of the sounds produced by the fuel metering pump of a parking heater as a function of the control voltage. Instrumental loudness values determined by an algorithm in accordance with DIN 45631/A1.

The results of instrumental loudness displayed in Fig. 6 largely reproduce the trend seen in the subjective evaluations illustrated in Figs. 2 to 5: Similar loudness for control voltages up to about 7 V, increase with control voltage from about 7 to 9 V and leveling off for higher control voltages. However, the slight increase at 11V seems to be somewhat more prominent in the instrumental evaluations, but is also seen in Figs. 3 and 5.

As concerns the magnitude of the loudness increase of the fuel metering pump with control voltage, the instrumental data (Fig. 6) suggest a factor of about 2.5. This value is in good agreement with the subjective evaluations for the anchor sound assigned 10 (Fig. 4), but somewhat larger than the factor obtained for the anchor sound assigned 100 (Fig.2). The comparison of subjective and instrumental loudness evaluations again stresses the advice given in section 3 to use in experiments with magnitude estimation at least two different anchor sounds.

5 DISCUSSION AND CONCLUSIONS

These days the sound quality plays an important part for the marketing of premium vehicles. Not only the overall sound quality but rather marginal details of sounds from ancillary components can lead to insistent complaints by demanding customers. As an example the rather faint sounds from the fuel metering pump of a parking heater are treated in this paper. The results obtained suggest that findings of extensive subjective loudness evaluations are largely reflected in instrumental analysis using algorithms in line with DIN 45631/A1.

From a practical point of view an important conclusion can be drawn from the study as follows: Usually the control voltage of the fuel metering pump is set to 8.5V. However, the parking heater works perfectly down to a control voltage of 6.5V. Therefore, just by reducing the control voltage by a factor of about 1.3, a substantial noise reduction can be achieved.

The data displayed in Fig. 6 for the instrumental loudness evaluation according to DIN 45631/A1 would seem to suggest a loudness reduction by a factor of 1.9sone/1.1sone = 1.73. Likewise, the results from the subjective evaluations using magnitude estimation with anchor sound as displayed in Fig.2 suggest a loudness reduction by a factor of 90/52 = 1.73. Moreover, subjective evaluations illustrated in Fig. 4 even would imply a loudness reduction by a factor of 22/10 = 2.2.

Results plotted in Fig. 3 suggest for a decrease in control voltage of the fuel metering pump from 8.5V to 6.5V a decrease in loudness by two categories, i.e. - - (softer). On the other hand, according to data in Fig. 5, an increase in control voltage from 6.5V to 8.5V goes with an increase in loudness by two categories, i.e. ++ (louder).

It is well known that a small reduction in control voltage of products like e.g. ventilators can lead to a substantial reduction of the loudness produced. In order to assess the magnitude of the loudness reduction quantitatively, subjective evaluations in psychoacoustic experiments would be the preferred approach. However, as seen also in this paper, predictions of loudness reduction using algorithms in line with DIN 45631/A1 can be helpful.

6 ACKNOWLEDGEMENTS

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