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FIELD MEASUREMENT OF VIBRATION LEVEL DIFFERENCE ACROSS VERTICAL JUNCTIONS IN A TIMBER FRAME BUILDING

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ABSTRACT: Reliable vibration level difference $D_{v,ij}$ data are necessary to accurately predict flanking transmission. In this paper we present the measurement of $D_{v,ij}$ we performed on two timber frame buildings and a selection of the obtained results. The measurements were performed according to ISO10848 with different excitation sources. The analysis focuses on both methodological aspects and constructive solutions. Methodological aspects comprise the comparison of the different excitation sources used (shaker, impact hammer, loudspeaker) and the discussion of the challenges related to mixed wall constructions in field situation. Constructive solutions include the assessment of a party wall compared to an outer wall and the possible mounting options for the inner plasterboard leaves, i.e., directly on the timber frame, on timber laths, on metal Z-profile and on metal resilient bars. Results show that hammer and shaker provide comparable and reliable excitation. The loudspeaker did not provide sufficient excitation. Mixed wall construction will lead to different values of $D_{v,ij}$. Sensor placement can help reducing the mixed effect, but the introduced uncertainty could not be evaluated in the field. Finally, the different mounting options of the inner plasterboard showed a potential improvement of more than 20 dB over a broad frequency range by replacing the direct installation on the timber frame with resilient bars, the other options performing in between.

KEYWORDS: flanking sound transmission, vibration velocity level difference, field measurements, experimental setup.

1 INTRODUCTION

Vibration level differences across a junction are required to predict flanking sound transmission [1, 2]. Several papers present laboratory measurements and the corresponding results, often highlighting the related challenges [3-6]. Measuring vibration level differences in the field is necessary to increase the knowledge and the amount of data set available for reference [7, 8]. However, field measurements must tackle uncertainties in the vibration transmission path. Suitable excitation is also needed, but not straightforward due to practical limitations and the risk of airborne excitation of other transmission paths. In the context of a research project aimed at developing a building system for 8 stories timber frame building, we performed several field measurements of vibration level difference. In this paper, we present a preliminary selection of the obtained results discussing methodological aspects and constructive solutions. We look i) at different excitation sources, ii) at the challenge in the field due to mixed wall assemblies and iii) measured vibration level differences with different solutions for the mounting of the inner plasterboard wall leaf. The paper is structured as follow; in chapter 2, we give a description of the measurement objects with the corresponding constructive details. In chapter 3, we give a brief overview of the measurement setup. In chapter 4, we present and discuss the results; 4.1 is about the comparison of the excitation sources, 4.2 is about the comparison of party wall and outer wall and the effect of mixed construction, 4.3 looks at the effect of resilient bars and metal Z-profiles, 4.4 compare the collected results with data from the literature. In chapter 5, we present our conclusions.

2 MEASUREMENT OBJECTS

We performed measurements at two apartment buildings under construction at two different locations, which we will refer to as location 1 (L1) and location 2 (L2). Figure 1 shows an outer view of location 1. Both buildings are erected using prefabricated timber frame modules. The two buildings have comparable load bearing structure but different wall and floor assemblies.

Figure 1: Outer view of one of the two buildings used for the measurements.

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At each location, we performed the measurements between two apartments with identical floor plan located above each other and including a party wall (W1) and an outer wall (W2). In this paper, we restrict the analysis to the vertical wall-wall transmission. The floor plans and the considered walls are shown in Figure 2 and Figure 3.

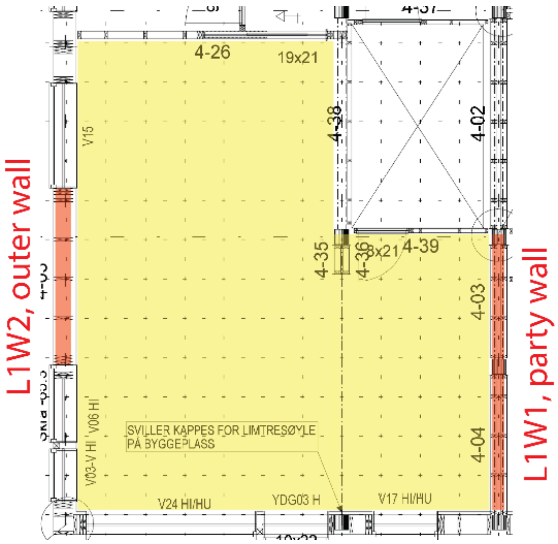

Figure 2: Floor plan of the apartment used for the measurements at location 1. The investigated walls L1W1 and L1W2 are highlighted.

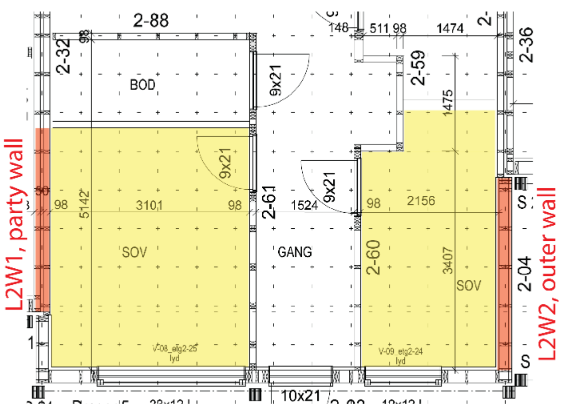

Figure 3: Floor plan of the apartment used for the measurements at location 2. The investigated walls L2W1 and L2W2 are highlighted.

The two locations used the same type of elements but with different solutions for the interior wall cladding and for the floor assembly. The wall assemblies are given in Table 1. The respective cross sections are shown in Figure 4 and Figure 5. The main difference between the two locations is the mounting method chosen for the inner plasterboard. At location 1, metal resilient bars (L1W1) or metal Z-profiles (L1W2) were used. At location 2, the plasterboard was screwed on the timber laths installed on the main wall frame. Figure 6 shows a horizontal section for location 1, where both the party wall and the outer wall are visible and a picture of the party wall with the resilient bars.

Table 1 Wall assemblies at the two locations.

Location 1	Location 2
Party wall (one side)	
2x 13 mm plasterboard 9 kg/m^2	2x 13 mm plasterboard 9 kg/m^2
25 mm resilient bar	1 x 11 mm chipboard
98 mm timber lath	98 mm timber lath
Outer wall	
2 x 13 mm plasterboard 9 kg/m2	13 mm plasterboard 9 kg/m2
50 mm steel Z-profile	48 mm timber lath
295 mm beam / insulation	225 mm beam / insulation
11 mm OSB board	11 mm OSB board
12 mm bitumen impr. fibreboar	12 mm bitumen impr. fibreboar
exterior cladding	exterior cladding

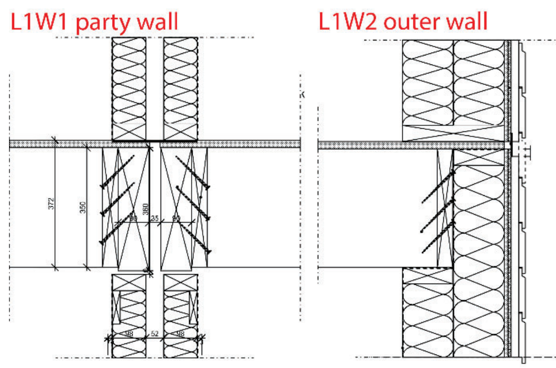

Figure 4: Cross section at the party wall and at the outer wall for location 1. See Table 1 for correct wall assembly.

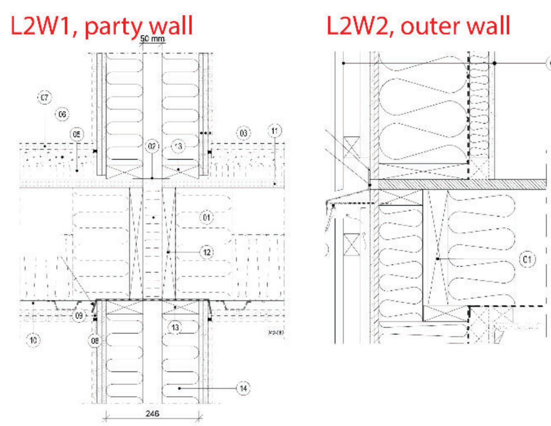

Figure 5: Cross section at the party wall and at the outer wall for location 2. See Table 1 for correct wall assembly.

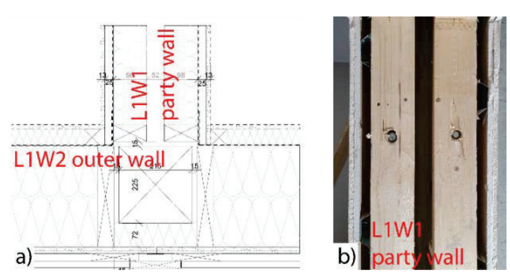

Figure 6:
a) Horizontal section of the walls at location 1. See Table 1 for correct wall assembly.
b) Picture of L1W1 showing the plasterboard installed on the resilient bars.

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3 MEASUREMENT SETUP

We designed the measurements with two main objectives; the first was to test and gain experience with the measurement method itself. The second was to collect data for further reference and further development of the constructive solutions. We performed the measurements according to the standard ISO10848 [1]. We defined measurement positions on both wall and floors. We measured the acceleration simultaneously on the sending and receiving side by means of several accelerometers that were moved at different locations. We used at least 9 measurement positions and two excitation positions, totalling at least 18 measurement positions per surface. Excitation and measurement positions were chosen both on wall studs and in between. The velocity was calculated by integration of the acceleration signal. We used different type of excitation; instrumented hammer, electrodynamic shaker driven with white noise, loudspeaker, and standardized tapping machine. The latter will not be discussed further here. Figure 7 gives an overview of the expected transmission paths and the sensor placement and the assignment of the codes D, d, F, f to the building elements. Figure 8 shows the shaker installed in front of the wall at location 1 and the accelerometers distributed on the surface. The yellow circles are excitation positions (5) while the blue circles, solid and dashed are the two groups of measurement positions used (2 x 6), totalling in this case to 60 measurement positions. $D_{v,Ff}$ was calculated from the average over all source and receiver positions according to the procedure described in the standard. In all figures presenting the results, the plotted line represents the vibration level difference and the area above and below the line represent the standard deviation.

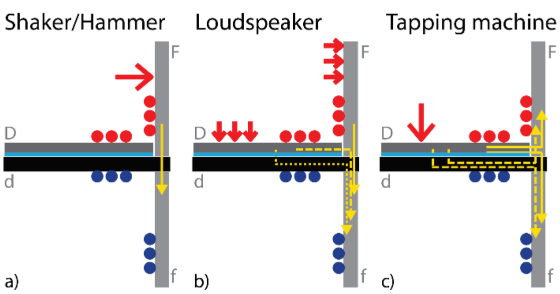

Figure 7: Excitation and expected main transmission paths.

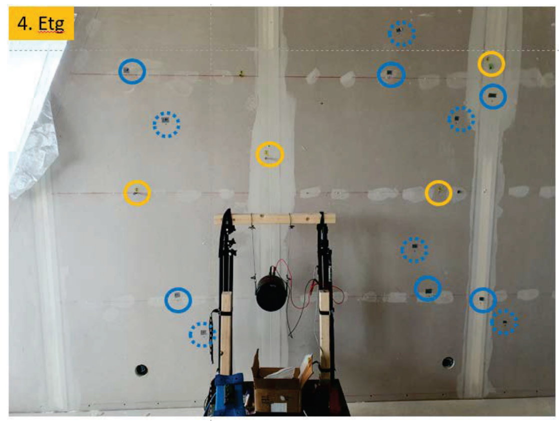

Figure 8: Shaker and accelerometers on the sending side.

4 RESULTS AND DISCUSSION

4.1 EXCITATION SOURCES

Figure 9 shows a comparison of the $D_{v,Ff}$ measured on the same partition with excitation from three different sound sources: hammer, shaker and loudspeaker.

The data show that hammer and shaker excitation provide comparable results, well within the standard deviation range. The measured $D_{v,Ff}$ with loudspeaker excitation clearly deviates from the other two sources. The loudspeaker was driven with typical levels for building acoustics measurements ($L_{A,eq}$ in the order of 95 dB). A closer look at the vibration velocity data on the receiving side revealed that the loudspeaker did not provide sufficient excitation; the generated vibration levels did not exceed the background level on the receiving side. The measured $D_{v,Ff}$ is therefore erroneous and too low. Also not shown, but important to note the measurement in the opposite direction, delivered comparable data for each source type. The results from the measurements performed at location 2, show the same trend: the loudspeaker did not deliver enough energy and the measured $D_{v,Ff}$ is lower than it should as shown in Figure 10.

We can draw two main conclusions; first, suitable excitations are hammer or shaker excitation. Loudspeaker it is not a suitable source. Secondly, a maybe natural remark on the quality check of the data: it is important to measure the background noise levels and plot them along with the excited vibration levels to verify that sufficient excitation was provided. A simple check that the measured values in the two directions are comparable might lead to a wrong assessment.

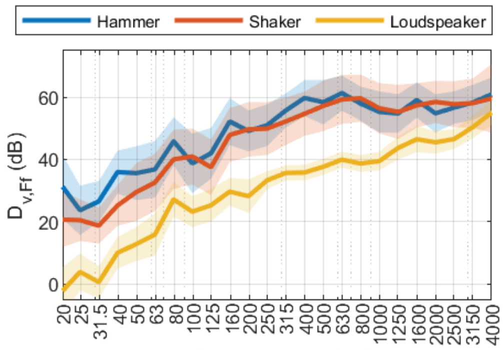

Figure 9: Vibration level difference measured on the L1W1 wall (path Ff) with hammer, shaker and loudspeaker excitation.

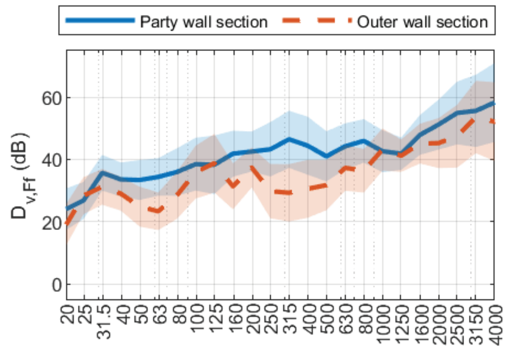

Figure 11: Vibration level difference measured at L2W1. The larger portion of this wall is a party wall.

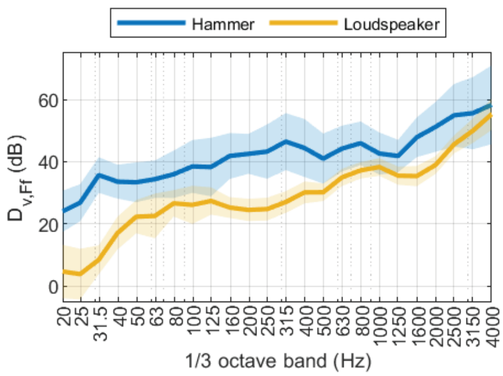

Figure 10: Vibration level difference measured on the L2W1 wall (path Ff) with hammer and loudspeaker excitation.

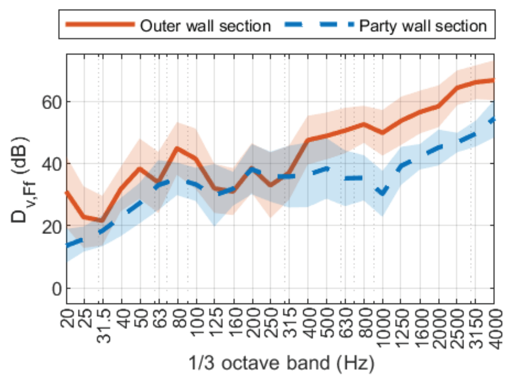

Figure 12: Vibration level difference measured at L2W2. The larger portion of this wall is an outer wall.

4.2 DIFFERENT WALL TYPES AND MIXED WALL ASSEMBLIES

When measuring in the field, it rarely happens that conditions are ideal. A challenging example was the situation at location 2. Both the party wall and the outer wall which were available to perform measurements presented mixed constructions as shown in Figure 3. Both walls had a portion that was party wall and a portion that was outer wall, although in different ratios. L2W1 was primarily a party wall and L2W2 was primarily an outer wall. The visible plasterboard layer covered over the two different portions at both walls. We chose to place several measurement positions on the larger portion and have one measurement position on the minor portion as a control point. We excited the wall within the major portion. In Figure 11 and Figure 12, we show the obtained results for L2W1 and L2W2 respectively. The continuous line is obtained from the measurement position on the larger portion and the dashed line from those on the minor portion.

The results in Figure 12 show that there are clear differences between the two different portions of the wall. The measured $D_{v,Ff}$ for the outer wall portion above 500 Hz exceeds by more than 20 dB the $D_{v,Ff}$ measured for the party wall portion. Differences between the two portions of the wall are also observed in Figure 11 but the trend is not as clear as on Figure 12; the $D_{v,Ff}$ measured for the two portions fall within the standard deviation range in large part of the frequency range. We observe the larger deviations in the frequency range 200 – 800 Hz.

In Figure 13, we compare $D_{v,Ff}$ for the party wall (main portion of L2W1) and the outer wall (main portion of L2W2). We observe the same trend as in Figure 12: the vibration transmission along the party wall seems to be stronger (lower $D_{v,Ff}$) than along the outer wall. However, the difference is not as strong as observed in Figure 12. An exception is the range 100-350 Hz where the transmission appears to be stronger along the outer wall.

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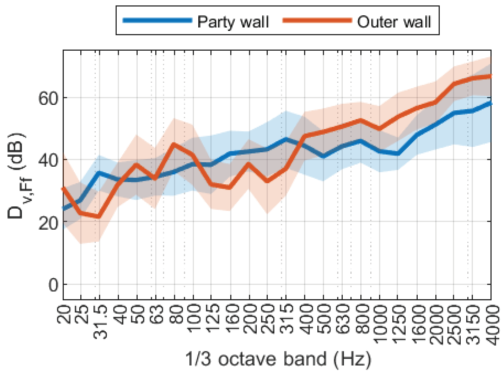

Figure 13: Vibration level difference measured at location 2 for the party wall (L2W1) and the outer wall (L2W2).

In this section, we looked at measurement performed on walls that had different construction on different portions. The results showed that it is possible to observe the differences between the different portions by placing the accelerometers well within the corresponding area. However, with the available data we cannot assess the measurement uncertainty that it is introduced in this kind of situation.

4.3 EFFECT OF RESILIENT BARS AND Z-PROFILES.

We performed the measurements at two locations (L1, L2) on two wall types: party wall (W1) and outer wall (W2). The respective basic wall structure was comparable at the two locations while the installation of the inner plasterboard was different. At location 1, the plasterboard was installed by means of resilient bars on the party wall (L1W1) and Z-profiles on the outer wall (L1W2). At location 2, the plasterboard was screwed directly on the timber framing both on the party wall (L2W1) and the outer wall (L2W2).

Figure 14 shows the comparison between the measured $D_{v,Ff}$ for L1W1 and L2W1, showing the effect of the resilient bars. The results show clearly that the resilient bars increasing effectively $D_{v,Ff}$ in the frequency range 125-2500 Hz by 10 to 20 dB. The resilient bars seem to have no effect at lower and higher frequencies. At frequencies close to 40 Hz, the $D_{v,Ff}$ measured on the wall with resilient bars is lower than that for direct installation; this might have to do with the resonance frequency of the system.

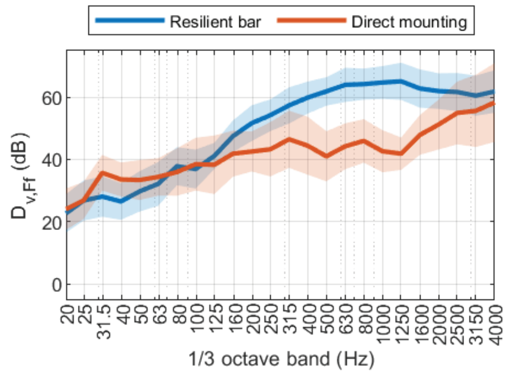

Figure 14: Vibration level difference measured on the party wall the two locations with hammer excitation. With resilient bar: L1W1. Direct installation: L2W1.

Figure 15 shows the comparison between $D_{v,Ff}$ for the outer walls at location 1 and 2 (L1W2, L2W2) and the effect of the Z-profiles. The $D_{v,Ff}$ below 100 Hz are comparable. Between 100 Hz and 1250 Hz, $D_{v,Ff}$ for L1W2 is up to 5 to 20 dB higher than for L2W2. This result shows that the Z-profiles effectively dampen the vibration transmission from the inner plasterboard to the wall structure, but on a reduced frequency range compared with the resilient bars.

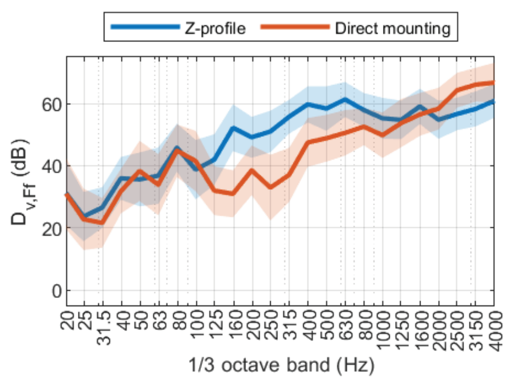

Figure 15: Vibration level difference measured on the party wall the two locations with hammer excitation. With Z-profile: L1W2. Direct installation: L2W2.

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4.4 COMPARISON WITH DATA IN THE LITERATURE

Homb in [8] published $D_{v,Ff,n}$ values from an experimental setup and compared with several other published data. In Figure 16 we compare the measurements results from our measurements with a relevant one from the datasets in [8].

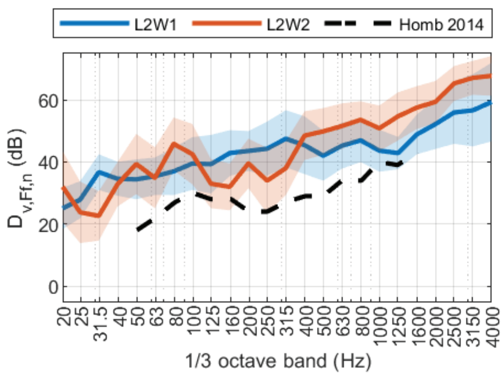

Figure 16: Comparison of the results for L2 with data from the literature [8].

The comparison shows that the measured values at location 2 are 10 – 15 dB higher than those from the referenced paper. The main difference between the measurement objects was the installation of the plasterboard: at location 2 the plasterboard is screwed to horizontal laths which are screwed to the load bearing timber frame. In the reference the plasterboard was screwed directly to the timber frame. This leads to at least two relevant differences; i) the horizontal laths influence the vibration field in the plate and ii) there is an additional vibration transmission reduction at the interface between the laths and the beam of the timber frame due to the connection loss. The combination of the two effects justifies the observed difference in the $D_{v,Ff,n}$ values.

5 CONCLUSIONS

We performed $D_{v,Ff}$ measurements at two different buildings erected as timber frame. The collect data and experiences allow to draw conclusions at two levels; at a methodological level and in terms of reference data for practitioners.

The methodological conclusions we can draw are:

- Hammer or shaker are convenient excitation sources. They deliver comparable results.
- Loudspeaker excitation with typical sound pressure level was not sufficient to measure vibration level differences in the field situation.
- Background noise on the receiving side must be monitored during measurements and included in the analysis to ensure reliable data.
- Mixed wall assemblies in field situation are a challenge that might limit measurement reliability. By choosing appropriate measurements positions, it is possible to observe significant differences. With our measurement setup, we could not quantify the uncertainty that this situation introduces.

The collected data can be used as reference in further projects. The collected data and the comparison with data from the literature showed that, assuming the same wall assembly in the sending and receiving room:

- Installation of plasterboard on horizontal timber laths, gives a broadband vibration transmission reduction in the order of 10 to 15 dB compared to direct installation on the frame.
- Installation of plasterboard using metal Z-profiles, gives a vibration transmission reduction in the range between 100 Hz and 1250 Hz in the order of 5 to 20 dB compared to the installation on the laths.
- Installation of plasterboard using metal resilient bars, gives a vibration transmission reduction in the range between 100 Hz and 2500 Hz in the order of 10 to 20 dB compared to the installation on the laths.

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