DEVELOPMENT OF A CONTINUOUS WOOD SURFACE CHARGE DETECTION DEVICE

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Abstract. Almost all woodworking processes involve mechanical friction and contact electrification, ie triboelectrification, between the wood surface and the woodworking tool. An electric charge is transferred from one solid surface to another when two materials come into contact with each other. Currently, there is no continuous inline-capable electrical surface charge measuring devices. The goal of this work was to create a measurement setup that can be used with a variety of woodworking processes. The proposed continuous surface charge detection (ConSurChaD) device connects an electric fieldmeter to a Faraday cage-style measuring box. Individual elements of the box can be mounted or dismounted to fit various woodworking processes. The application of electrostatic induction principles permitted quantification of the electrostatic surface charge by measuring the accumulated electric field strength generated, expressed in kV/m. The device was compared with a reference method using a commercial discontinuous detection approach. Measurements were made simultaneously using an electrostatic voltmeter, a hand-held instrument that measured the surface charge in volts. The validation confirmed the accuracy of the ConSurChaD device ensuring the applicability for continuous measurement of electrostatic surface charges. This approach allows for a more efficient and targeted application of triboelectrification to wood surfaces, leading to improved surface coatings and other enhancements.

Keywords: Contact electrification, electric fieldmeter, electrical field strength, triboelectrification, woodworking.

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INTRODUCTION

When materials with solid surfaces come into contact, an electric charge is transferred from one surface to the other, a phenomenon called frictional electricity, contact electrification, or triboelectric charging. The imbalance of the electrostatic charge becomes evident when the materials are again separated. As equal and opposite charges result on the two charging partners, the polarities depend on the effective surface work functions of the two materials (Lowell and Rose-Innes 1980; Greason 2013). The surface work function is the minimum amount of energy required to remove an electron from a solid (Kelly and Spottiswood 1989; Kittel 1996). The consequence of this electron transfer is that the participating materials become oppositely charged. Matsusaka et al (2010) proposed that the amount of net transferred charge, denoted as Δq_C, is determined by the product of the capacitance between the two contacted materials, and the contact potential difference. The net transferred charge Δq_C can be therefore calculated, according to Harper (1951; Eq 1):

$$\Delta q_C = C_0 \frac{-(\varnothing_w - \varnothing_m)}{e} \quad (1)$$

where $\varnothing_m$ is the surface work function of the colliding processing tool and $\varnothing_w$ is the effective work function of the given material. The effective surface work function differences between two surfaces drive the charge transfer, and this charge transfer will cease when the energy levels of the two materials become equal (Matsusaka et al 2010). Although extensive research exists on contact electrification, or triboelectric charging, of metals or polymers, very little is known about the triboelectric surface charging of wood, which is reviewed as follows.

Triboelectric Charging of Wood Surfaces

According to Skaar (1988), wood is semiconductive with the conductivity varying with wood density and MC. When it contacts a machine, wood acts mainly as an insulator. Previous studies showed that contact electrification occurs during wood sawing, cutting, chipping, shredding, or defibrating (Myna et al 2021a, 2021b). We further found electrical surface charges on the wood are generated when the surfaces are brushed (Leiter et al 2022).

The triboelectric series provides insights into the behavior of any material in various applications involving static electricity and charge transfer. A triboelectric series is a list of materials that are ranked by their tendency to gain or lose electrons, and how effectively these charges are exchanged relative to their position within the list (Diaz and Felix-Navarro 2004; Park et al 2008; Burgo et al 2016; Zou et al 2019). The position of a material in the triboelectric series indicates the polarity of the generated charge when two materials are contacted and again separated (Zou et al 2019). A material that donates an electron becomes positively charged and appears on the positive side of the colliding partner. Materials positioned further apart in the series have been found to show higher specific charges (Diaz and Felix-Navarro 2004). Wood is generally positioned near the middle of the triboelectric series, which means it tends to be relatively neutral but can behave as either an electron donor or acceptor, depending on the other materials it comes into contact with (Diaz and Felix-Navarro 2004). For example, Greason (2013) reported that wood becomes charged positively when colliding with a metal.

The underlying triboelectric charging mechanisms, particularly concerning semi insulating materials, including wood, are discussed by Karner and Urbanetz (2013). Myna et al (2021b) discussed triboelectric charging of wood dust particles generated during hand-held circular sawing. Further, Myna et al (2021a) have shown that selected saw blade surface coatings reduce dust formation during wood processing, an idea that was also patented (EP 3 881 958 A1). Leiter et al (2022) modified the measurement setup introduced by Myna et al (2021b), for examining solid wood surfaces instead of wood dust particles, to investigate triboelectric surface charges caused by surface brushing. The following methods can be listed to accurately measure surface electrification: 1) Electrostatic voltmeter measurements: This contactless method measures the electrostatic potential on the material surface after contact or friction, providing direct insights into the triboelectric charge accumulation (Pandey et al 2009). 2) Faraday cup experiments: An isolated conductor (Faraday cup) captures charges transferred during contact or separation from a material, measuring the total transferred charge directly to quantify triboelectric charging. Using a Faraday cage is a well-established measuring method for triboelectrification (Chen et al 2023). 3) Surface charge density measurements: Techniques such as kelvin probe force microscopy can map the surface potential at the microscale, revealing charge distributions and densities resulting from triboelectric charging (Noras and Pandey 2010). The charge-to-mass ratio works well for the investigating particles or smaller samples however, it is inappropriate for examining a 3D material's surface charge (Zou et al 2019). They suggested a technique that excludes air pockets at the surface-to-surface contact between two solid materials by using liquid mercury. 4) Current and voltage measurements: this method refers to directly measuring the current or voltage generated between two materials during or after contact (Ziegler et al 2009). 5) Electron spectroscopy methods, including X-ray photoelectron spectroscopy, auger electron spectroscopy, or UV photoelectron spectroscopy, which all analyze emitted electrons (Rivière 1990; Michler 2023). Finally, 6) X-ray powder diffraction can visualize charge distributions following triboelectrification (Kato and Tanaka 2016).

Triboelectric charging of wood surfaces holds potential as a process parameter for controlling surface properties such as conductivity and friction, thereby improving adhesion during coating or surface finishing. This approach requires continuous monitoring of the surface charge status to ensure optimal results. Current surface charge detection devices are unsuitable for continuous measurements and cannot be integrated into inline production processes. We introduce continuous surface charge detection (ConSurChaD) device, capable of being used in woodworking processes. The device was designed to be mobile, and capable of continuously recording triboelectric charges near equipment such as saw blades, brushes, or sanding belts. We have developed a universally applicable method, which is described here in detail and compared with a commercially available, discontinuous detection method. We hypothesize that this new continuous detection device can deliver reliable data, ensuring its suitability for use in woodworking processes.

DEVICE DEVELOPMENT

The main element of the ConSurChaD device consists of a 15×20 cm aluminum measuring box, built as a Faraday cage to shield the electrostatic charge. The different elements of the box, as well as the wings and legs, are individually mounted or dismounted with screws. The box has a ground distribution to ensure that all elements are constantly grounded, and an arm through which the connected cables (Bayonet Neill-Concelman (BNC) connector and ground) can be passed to ensure safe operation. The device is equipped with an electric fieldmeter (EFM) 115 electrostatic fieldmeter (Kleinwächter®, Hausen im Wiesental, Germany), for contactless detection of electrical surface charges. This compact and sensitive fieldmeter accumulates voltage readings, based on the field-mill principle (Boldyrev et al 2016). Figure 1 displays the device: (1a) top view, (1b) elevation view, and (1c) side view, as well as a (1d) 3D model and in (1e) the elements of the measuring box. The connector head to attach the EFM via a BNC cable was linked to the metal detection plate. As the Faraday casing was electrically isolated, the detected electrical charges were shielded from potential electrostatic charges of the surroundings. The detection plate has a thickness of 3 mm. Electrostatic induction, which is the displacement of charges (electrons) in the metal plate, occurs when an electrically charged surface including wood emits an electric field (Donnevert 2020). This charge displacement was transmitted by the metal cylinder to the connector head and then to the EFM via the BNC cable. The fieldmeter was attached to a personal computer, which operated the readout software (EFMXX5_ReadOut, Kleinwächter®). The measurement range was set to either 5 kV/m or 25 kV/m, based on pretests, with a zero-calibration that had to be performed before every second

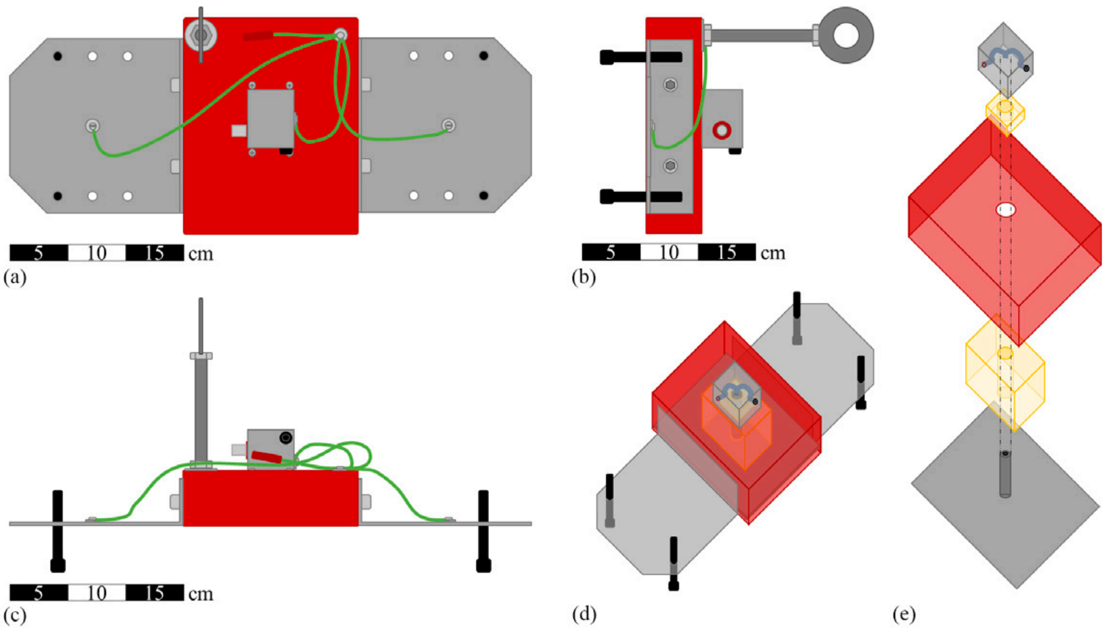

Figure 1. Continuous surface charge detection device (a) top view, (b) elevation view, (c) side view, (d) 3D model, and (e) elements of the measuring box with the dimensions of 15 × 20 cm (top to bottom): connector head to attach the EFM, insulating polytetrafluorethylene cube, Faraday casing, insulating polymer cube, and detection plate – connected to the top box along the dotted lines. EFM, electric fieldmeter.

set of measurements. Grounding was engaged throughout, to ensure that only wood surface charges were recorded, without measuring electric fields from the conveyor belt or the surroundings. Thus, a photo sensor was also installed between the triboelectrification tool (eg brushes) and the ConSurChaD device to deactivate and activate grounding. Surface charges were measured, and the grounding was turned off when the photo sensor detected a moving sample on the conveyor.

The electric circuits of the device are illustrated in Fig 2. The photo-sensitive barrier ensured a continuous flow of protons between the transmitter and the receiver of the photo sensor. The control

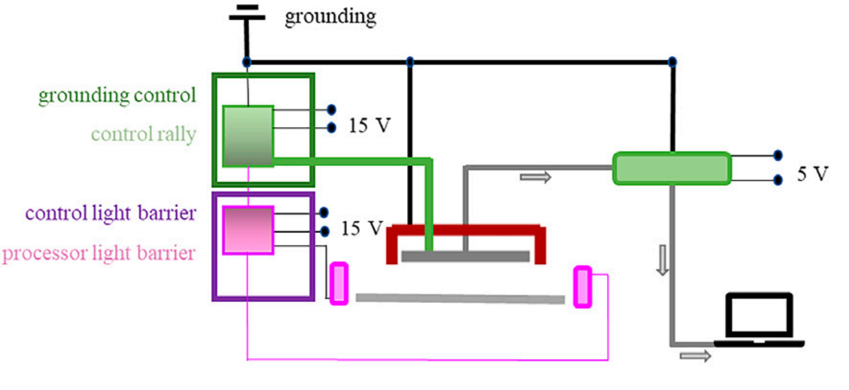

Figure 2. Electrical circuits of the continuous surface charge detection device.

light barrier sent a signal to the grounding control when a wood sample interrupted the proton flow. As a result, the measuring plate's grounding was turned off, allowing triboelectric field strength measurements. The proton beam was built up again when the wood sample left the area of the light barrier, and the control light barrier notified the grounding control to reactivate the measuring plate grounding, and thus stop field strength measurement. The accumulated electrostatic surface charges were measured at a resolution of ±5 V/m as the electric field strength.

The adjustable ConSurChaD device allowed precise positioning above-measured wood surfaces at set distances by mounting suitable wings and legs. Two variables impacted the results: the distance between the detection device and the measured object, and the sample size. First, the detected surface charge weakened when the measuring distance exceeded the initial setting and strengthened when it was shorter. Second, the devices used to measure surface potential assumed the object under measurement had an infinite size. The device delivered repeatable values when the measured objects were noticeably larger than the ConSurChaD device detection area.

VERIFICATION RESULTS

Three Norway spruce (*Picea abies* (L.) Karst) samples 25 mm wide, 600 mm long, and 25 mm thick, were prepared. Samples were conditioned at 20°C and 65% RH. Mechanical friction was applied to triboelectrically charge the solid-wood surfaces using a commercial brushing machine (TWINGO 300 B, Houfek a.s., Czech Republic). Figure 3 shows the installed ConSurChaD device as used in the conducted experiments. The experimental design included five sets of three samples ($n = 15$), which were brushed at four different machine settings, two different brush pressures, and at two different feed rates: 1) high brush pressure and fast feed rate, 2) high brush pressure and slow feed rate, 3) low brush pressure and fast feed rate, and 4) low brush pressure and slow feed rate. The wood samples were sanded and set aside between each of the five sample sets to ensure that the next set started with a fresh,

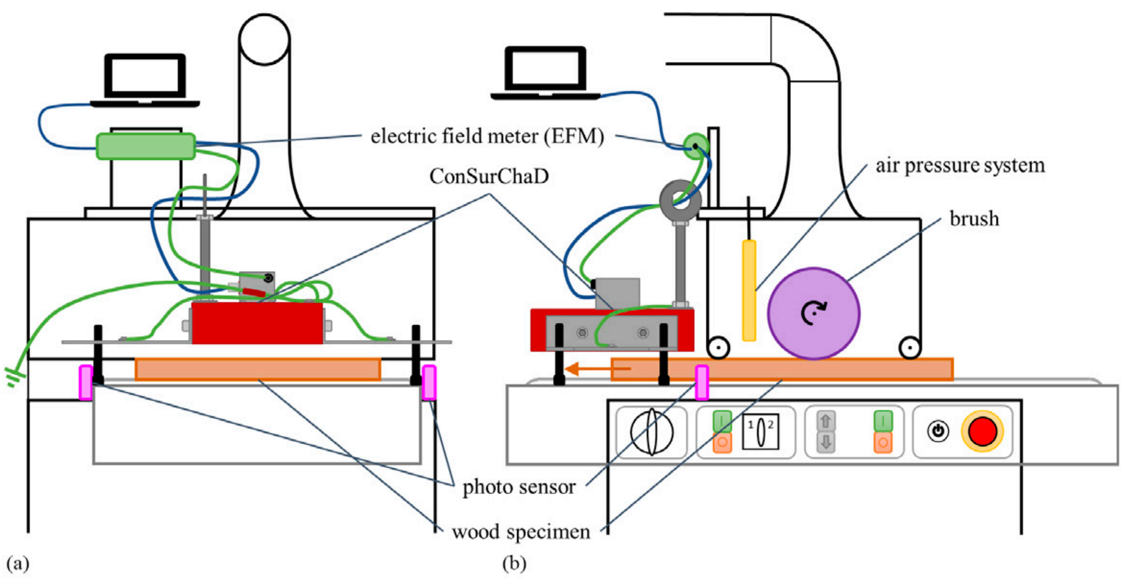

Figure 3. An experimental setup was used to measure the surface charges of wood samples caused by surface brushing: (a) side view and (b) elevational view. ConSurChaD, continuous surface charge detection.

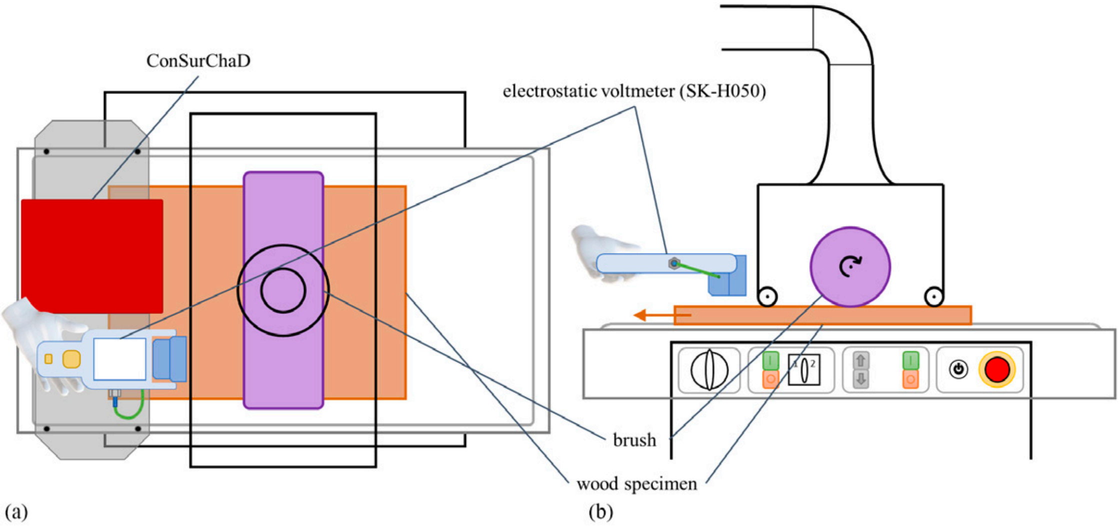

Figure 4. The top view of simultaneous measurement shows the ConSurChaD device and the Keyence SK-H050 reference (a); the elevational view of the brushing machine with the surface-charge measurement, with the installed Keyence device (b). ConSurChaD, continuous surface charge detection.

charge-free surface. As shown in Fig 4, surface charge measurements were simultaneously taken directly after brushing, using the new ConSurChaD device as well as an SK-H050 electrostatic voltmeter (Keyence, Belgium) as the reference method. The SK-H050 made it possible to measure the minimum and maximum surface charge over a period as well as the charge at the end of the measurement period. Unfortunately, the measured values between starting and ending the measurement could not be continuously stored. The SK-H050 measured the surface charge in volts at the set distances of 25 mm for higher accuracy, or 100 mm for a larger detection field, at an accuracy of ± 10 and ± 25 V, respectively, depending on the chosen distance (Keyence Corporation 2010).

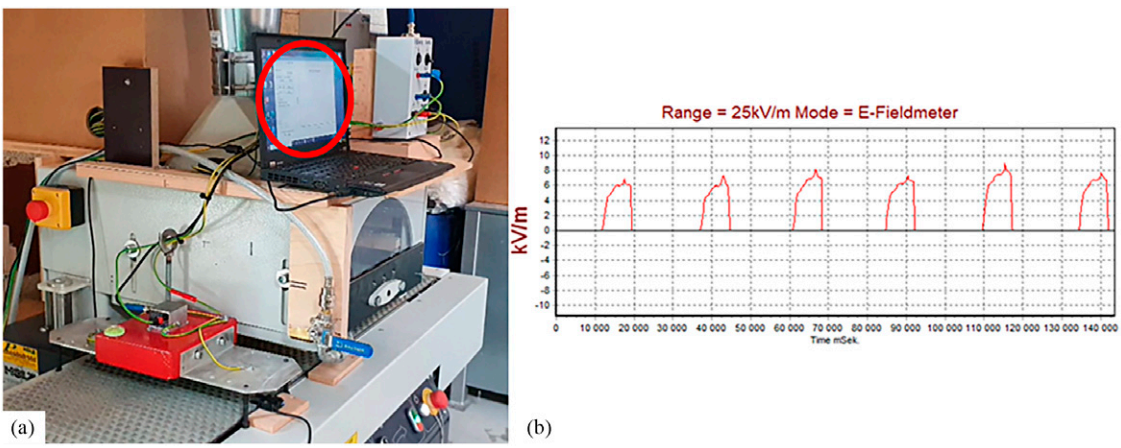

Figure 5. Setup (left) and data plot as produced with the readout software (right) plotting the electric field strength [kV/m] of three samples getting brushed twice.

Table 1. Verification of the self-designed ConSurChaD device with the electrostatic voltmeter SK-H050 (Keyence, Belgium) ($n = 15$).

Measurement method	ConSurChaD				Reference			
Brush pressure	High	High	Low	Low	High	High	Low	Low
Feed rate	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
μ [V]	—	—	—	—	139.5	172	67	136.5
σ [V]	—	—	—	—	31.4	25.8	12.8	19.5
μ [kV/m]	5.81	6.73	2,84	5.31	5.58[a]	6.88[a]	2.68[a]	5.46[a]
σ [kV/m]	1.6	1.36	0.55	0.9	1.67[a]	1.49[a]	0.53[a]	1.11[a]

[a]Converted into kV/m by dividing trough the distance of 25 mm.
ConSurChaD, continuous surface charge detection.

Since higher measurement accuracy was attained, the measuring distance of 25 mm was chosen as the baseline setting for verification.

Figure 5 shows the measurement of the cumulated electric field strength of three samples getting brushed twice. Outcomes from the ConSurChaD and reference methods are displayed in Table 1. The reference data were converted into kV/m for better comparison. It became evident that the two methods did not differ significantly, by a two-way ANOVA using SPSS® Statistics 26 (IBM Deutschland GmbH, Böblingen, Germany) ($p > 0.05$). However, significant differences ($p < 0.05$) were found between the settings (Fig 6). The validation showed that the range of measurement inaccuracies was the only difference between the two results. Overall, it can be concluded that our hypothesis was confirmed. The new continuous detection device delivers reliable data, ensuring its suitability for woodworking processes.

CONCLUSIONS

The correct determination of the electrostatic surface charge on wood was achieved using a self-designed ConSurChaD device. A comparison with readings from a discontinuous reference method showed that the differences were within the range of measurement variations, confirming the accuracy of the ConSurChaD device. This enables applications in continuous woodworking processes, allowing triboelectric charging to be

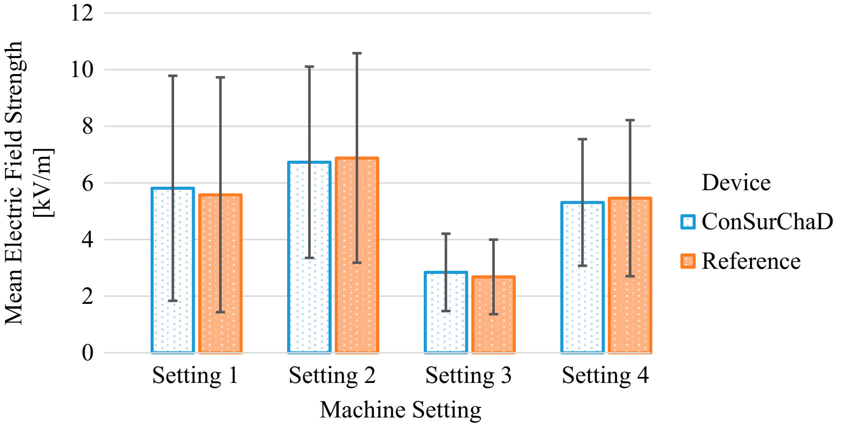

Figure 6. Comparison of electric field strength measurements with the newly developed ConSurChaD device, compared with the Keyence SK-H050 reference. Mean and standard deviations of electric field strength in kV/m are shown, using the machine setting high brush pressure and fast feed rate (1); high brush pressure and slow feed rate (2); low brush pressure and fast feed rate (3); and low brush pressure and slow feed rate (4) ($n = 15$). ConSurChaD, continuous surface charge detection.

applied to wood surfaces to enhance their properties, such as surface conductivity, surface friction, or enhance adhesion for coatings or finishes.

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