Anthropometric Considerations for Designing a Test Finger to Avoid Electrical and Mechanical Hazards

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ABSTRACT

Standardized test fingers are used for testing products against mechanical and electrical hazards. The most common one is given in EN 61032. An application for this test finger is the classification of enclosures by the IP (International Protection) - Code according to EN 60529 (2000). The dimensions of this test finger, mentioned in these standards, have remained unchanged for several decades. In the meantime the corresponding anthropometric dimensions of the human being have changed as well as the standard of safety and the level of safety awareness. Therefore, it has been investigated, whether the dimensions of the test finger specified in these standards are still in accordance with anthropometric considerations and whether they represent a sufficient level of safety. This article is based on a project, which has been performed on behalf of the Commission for Occupational Health and Safety and Standardization (KAN). By this article, the report is carried forward.

Keywords: Product testing, test finger, anthropometry, electrical hazards, mechanical hazards, safety

INTRODUCTION

During the last decades, significant changes in the work environment can be observed. Here, the standard of safety as well as the safety awareness could be increased significantly. This is reflected by the development of work accidents e.g. in Germany over a longer period shows this very clearly. Compared to the situation in the 1960s, the number of working accidents per 1.000 full-time employees in Germany decreased to about ¼. in 2011 (cf. Government report (2012)). Without successful prevention activities and active and passive safety measures, this continuously decreasing trend is difficult be explained.

In the same time, human body dimensions have changed more or less extensively. Buzzwords like "acceleration of body height" and "horizontal growth" describe these changes. They are reflected in both, an increase of the mean body longitudinal dimensions as well as in an increase of the mean circumference dimensions. This topic will later be discussed in more detail.

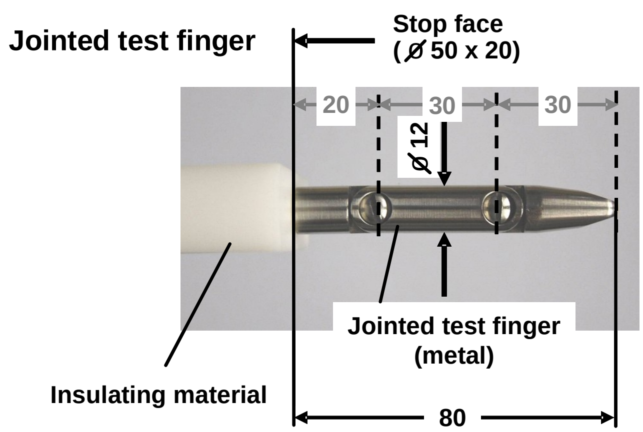
An analysis of occupational accidents in the commercial sector based on numbers given by the German Social Accident Insurance (DGUV) shows, that the hand is often still the injured part of the body. With 34.5 % in 2011 (corresponding to about 306,000 occupational accidents) more than every third occupational accident in Germany is affected. In 19 % of these cases the index finger is the relevant part of the body. In about half of these accidents superficial wounds and lacerations are observed (cf. Standke (2013)).

Summarizing these observations, it can be concluded, that since the dimensions of the standard test finger were established - presumably in the 1960s - significant changes of relevant body measurements are observed and must be taken into account. These facts raised the question, whether the existing dimensions and the associated testing is still able to ensure a sufficient and contemporary protection against electrical and mechanical hazards. Primary target group are employees, accordingly exclusively the protection of adult and juvenile persons are considered.

THE COMMON STANDARD TEST FINGER

What is the common standard test finger ? This question quickly leads to the European Standards EN 60529 (2000) and EN 61032 (1998). In these standards, an identical test finger is described. This test finger is shown in Figure 1. Main Characteristics are tripartism, taking account of the finger joints as well as a diameter of 12 mm and a length of 80 mm. Deviations from these dimensions may only be found in standards, if the protection of non-adult persons is to be tested. For this purpose, the standard EN 61032 (1998) provides probes with reduced diameter and length.

When focussing on occupational safety and health – and therefore focussing on the protection of adults - the jointed test finger presented in Figure 1 and its dimensions may be seen as the current state of the art.



length: (20 + 30 + 30) mm =	**80 mm**
diameter:	**12 mm**

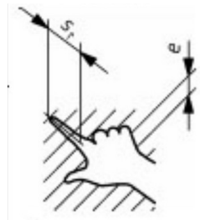
Figure 1: Dimensions of the jointed test finger according to EN 60529 (2000) and EN 61032 (1998)

SAFETY DISTANCES IN INTERNATIONAL STANDARDS

The international standard EN ISO 13857 (2008) specifies safety distances to prevent hazard zones being reached by the upper and lower limbs. As this standard is mandated under the Machinery Directive, in the EC this standard and its specifications are relevant for the safety of machinery and leads to the presumption of conformity.

Depending on size and type of a regular opening safety distances are indicated for reaching through by finger up to the finger root for persons of 14 years and elder. A distinction is made between slotted, squared and circulared openings. The given minimum distances should ensure that risk areas can not be reached by the finger up to the finger root (cf. Table 1).

Table 1: Safety distances to prevent reaching through regular openings by the finger acc. to EN ISO 13857 (2008)

part of the body	Image	size of opening e	Safety distance s_r		
			Slot	Square	Circle
finger up to finger root		6 < e ≤ 8	≥ 20		
		8 < e ≤ 10	≥ 80	≥ 25	≥ 20
		10 < e ≤ 12	**≥ 100**	**≥ 80**	**≥ 80**
		12 < e ≤ 20	**≥ 120**	**≥ 120**	**≥ 120**
		All values given in mm			

A comparison of the data given in Figure 1 and Table 1 shows, that the diameter of 12 mm can be found in both considerations. However, for openings larger than 12 mm (up to 20 mm), in EN ISO 13857 (2008) a safety distance of ≥ 120 mm is indicated. Compared to the common test finger with a given length of 80 mm, there is a significant difference of more than 40 mm.

Therefore the question is: which safety distance is appropriate and contemporary in view of the objectives for safe products? This can be checked by looking at the current anthropometric data situation. As indicated before, the relevant body dimensions to be analyzed are the length and the breadth of the finger close to the body (proximal). Although in general the middle finger has a greater length than the index finger, this is insignificant due to anatomical conditions. Consequently, the following investigations concentrate on the dimensions of the index finger.

ANTHROPOMETRIC DATA FOR FINDING SOLUTIONS

Anthropometric data collections

In the framework of this investigation, current distributions of relevant body dimensions were considered and compared with the dimensions of the common test finger. Since it is a check for safety-related measures, the relevant percentiles to apply are the first percentile for the diameter (resp. the breadth) and the 99th percentile for the length (cf. EN 614-1 (2009) or BGI 523 (2003)). As far as available, national as well as international distribution data were included in the evaluation. As relevant anthropometric data, the body measurements for index finger length and -breadth were considered.

The international Technical Report ISO/TR 7250-2 provides that kind of information for several ISO member bodies. The intension of this Technical Report is to gather the most current distributions for defined anthropometric dimensions for populations in ISO member bodies. As the collection of data started only a few years ago, the number of member bodies, who are already participating, is still fairly restricted.

Table 2 shows the distribution data from those ISO member bodies, which already provide data for the body measurements concerned. As far as available, the number of measurements of the underlying data base (N), the first (p1) and the 5th percentile (p5) of the index finger breadth (proximal) as well as the 95th (p95) and the 99th percentile (p99) of the index finger length is provided (cf. Mühlemeyer et al. (2012)).

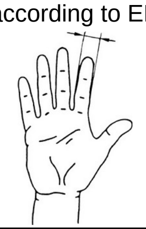
When looking closer at the distribution data given in ISO/TR 7250-2 (2013) it is noticeable, that there are quite a few gaps. Some countries, which are not considered in Table 2 have not yet been made available any information for the considered body measurements. In other cases (e.g. Germany) no information is provided about the size of the sample nor the first and 99th percentile. This is due to the fact, that in case of Germany the information are copied from the national standard DIN 33402-2 (2005), where these information are also missing. Looking at the distribution data from Thailand, also information about the first and 99th percentile are also not reported.

Table 2: Index finger breadth and Index finger length: relevant percentiles for populations in various ISO member bodies (data from data from ISO/TR 7250-2 with first supplement (E2012))

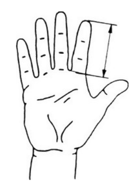
				Index finger breadth (close to the body)		Index finger length	
Population	**Country**	**Survey period of time**	**N**	**p1**	**p5**	**p95**	**p99**
male	Germany	1999 - 2002	-	-	19	83	-
	Japan	2004 - 2006	2,873	16	17	77	79
	Kenya	2006 - 2007	130	18	19	82	88
	Korea	2003 - 2004	2,611	16	17	77	80
	Thailand	2000 - 2001	1,246	-	15	85	-
	China	1986 - 1987	11,164	18	19	76	79
female	Germany	1999 - 2002	-	-	17	77	-
	Japan	2004 - 2006	2,456	14	15	72	75
	Kenya	2006 - 2007	73	15	17	80	87
	Korea	2003 - 2004	2,614	15	15	72	75
	Thailand	2000 - 2001	1,170	-	14	79	-
	China	1986 - 1987	11,150	16	17	72	76

Explanation of dimensions according to EN ISO 7250-1 (2010):

Index finger breadth, proximal
- Measure 4.3.5:



Index finger length
- Measure 4.3.4:



By analyzing the distribution data for the proximal Index finger breadth, given in Table 2, for the first percentile a range from 14 to 18 mm is observed. Therefore the choosen diameter of 12 mm for the test finger according to EN 60529 (2000) provides a high level of safety as also openings are tested, where more or less no adult person is able to reach through with her or his finger.

In contrast to the choosen diameter of the common test finger, its length must be seen critically. Here, the values for the 95th percentile is already up to 83 mm. Looking at the 99th percentile (cf. Table 2) this value is almost up to 88 mm. This circumstance has already been reported in an overview of anthropometric data in standards (Gebhardt et al. (2009)).

Besides this observation, we have to take into account, that the values given in Table 2 are measured in accordance with EN ISO 7250-1 (2010). These values are systematically smaller than the possiblity of reaching through openings by the finger up to the finger root. That´s because the measurement is defined as (just) the distance from the tip of the second finger to the proximal fingercrease on the palm of the hand (cf. EN ISO 7250-1 (2010)).

This leads to the assumption, that with a length of 80 mm, a significant number of (mostly male) people are not optimally covered and protected when using the common test finger. Therefore, there is a remark in the standard, that “the jointed test finger shall have adequate clearance from hazardous parts” (cf. EN 60529 (2000)). In contrast to the chosen diameter, the chosen length and its possible level of protection is clearly limited. In order to realize a consistently high level of protection, an adaption due to antropometric considerations is very much recommended (cf. Mühlemeyer et al. (2012)).

Of course we have to consider, that the observed discrepancy is only relevant for larger openings with more than 12 mm in diameter as for smaller openings the test finger will not pass through. This is in accordance with the required safety distances given in EN ISO 13857 (2008). Assuming square or circular shaped openings, for opening sizes of 10 to 12 mm, the required safety distance is at least 80 mm while the required safety distance is at least 120 mm for opening sizes of 12 to 20 mm (cf. Table 1). This also means, that in case of the classification according to the IP (International Protection) Code the classification IP 1XB is mainly affected (see also EN 60529 (2000)).

In order to find reasons for this discrepancy, besides a higher level of safety and safety awareness, the development of body measurements in the past decades should be investigated.

Development of body measurements

The development of body measurements during the recent decades may be summarized as follows: people are on average getting larger and wider. The shift of the mean value towards higher values naturally has also an impact on the marginal areas, that shifted in at least the same way. This refers to the German and European population, but also to large other parts of the world´s population. The first development is often described by the term "acceleration in length", the second development may be described by "horizontal growth". Especially in this area, also an advanced scattering is observed.

The observed increased growth in length mainly relates to the long bones, which also include the finger bones. Scheffler & Schüler (2013) show the increase in mean body height for adults in Germany. Since the 1950s, an increase in mean height for men of approximately 90 mm is observed, which corresponds to about 5%. A similar development may be observed also for women (see Figure 2).

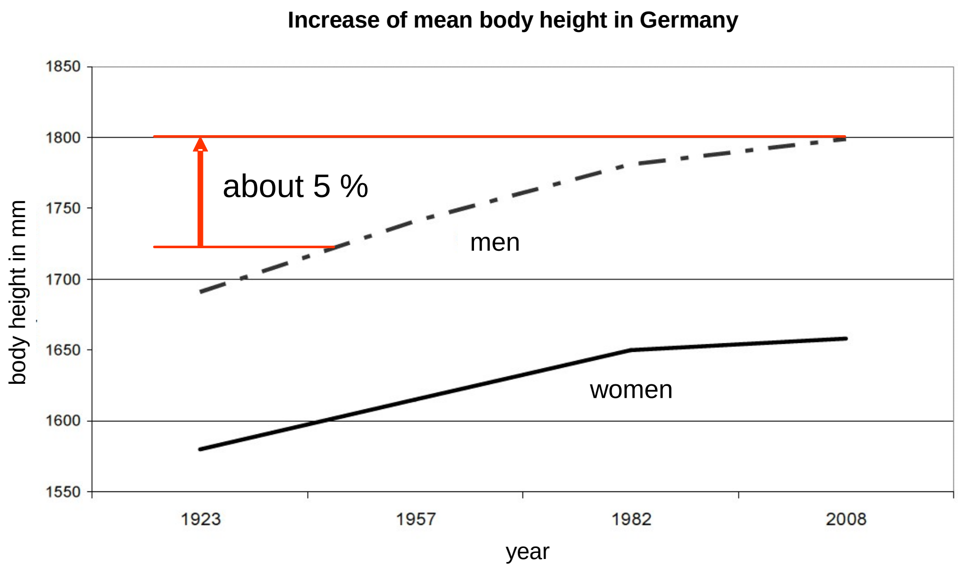


Figure 2. Increase of mean body height in Germany (from: Scheffler&Schüler (2013) with amendment)

According to experience this observation, which at first applies to the average longitudinal dimensions, is at least similar or even more pronounced for the edge regions of the distribution. Therefore the first and 99th Percentile are affected in an at least similar or even more pronounced way.

This may be confirmed by current measurements shown in Figure 3. Here the index finger (pass-through) length and the proximal index finger breadth were measured. In total 384 male as well as female subjects took part in the measurements. The measurements were carried out in Germany with regional focus on North Rhine-Westphalia (see also Wetzel (2012)).

The here given measurements for the “Index finger pass-through length" correspond more or less exactly to the required anthropometric value. Due to the fold of skin between the fingers, compared to the Index finger length defined in ISO 7250-1 (2010), on average the values measured here are about 5 mm larger.

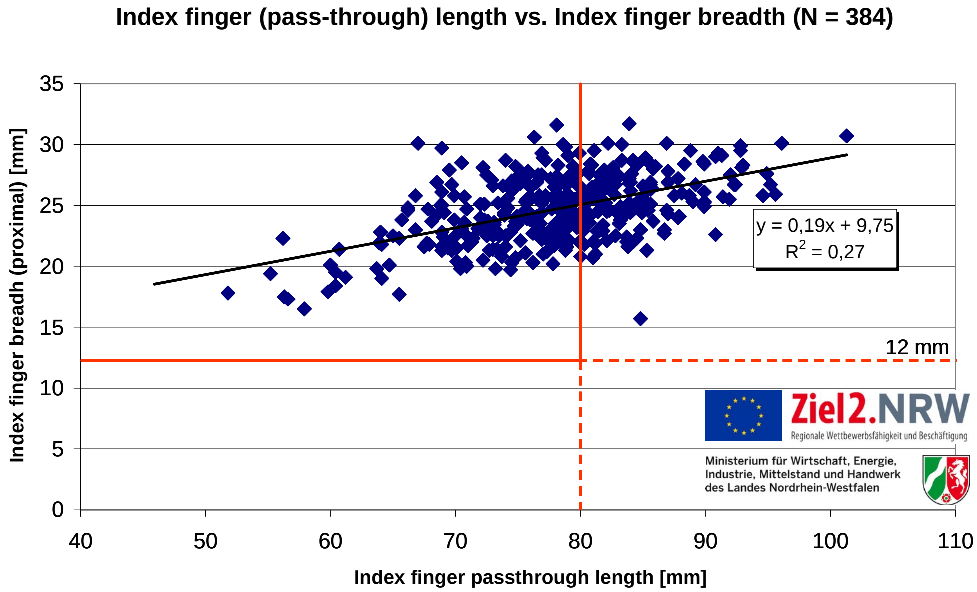


Figure 3. Index finger pass-through length vs. proximal Index finger breadth; Results from N = 384 measurements in the framework of a Ziel2-project

The lines in Figure 3 are also showing the dimensions of the current standard test finger (80 mm in length, 12 mm in diameter). Even for this small group of about 400 subjects, the presented data clearly show, that the selected length can not ensure an optimal protection. People with finger dimensions in the upper right quadrant are not optimally protected respectively potentially at risk. Simultaneously it can be shown, that for the same subjects the diameter of 12 mm may be seen as a good choice for a high level of protection for adult people.

CONCLUSIONS

Summing up the results of the investigation, it can be noted, that a diameter of 12 mm for a test finger still offers a high level of protection. Also the tripartism, taking into account the finger joints, is a very good approach for testing and simulating possible hazardous situations. However, the changes of the last decades, both in what concerns the anthropometric measurements as well as the safety standard and safety awareness, seems to require an adaptation of the length of the test finger to ensure the same level of safety protection as the chosen diameter.

A proposal has been derived taking into account these considerations (see Figure 4). The proposal starts from the largest 99th percentile of the Index finger length given in the current ISO/TR 7250-2 (2013), which is about 90 mm (see Table 2). The proposal further takes into account the following safety-enhancing supplements:

- the fact, that so far data from only very few ISO member bodies are available, is considered by a supplement of 10 mm,
- the fact, that by measures in accordance with EN ISO 7250-1 (2010) the potential depth of penetration is not fully reflected, is considered by a further supplement of 5 mm,
- the fact, that fingernails may increase the index finger length, is considered by a further supplement of 5 mm.

Anthropometric considerations for designing a test finger to avoid electrical and mechanical hazards lead to a minimum length of (90 + 10 + 5 + 5) mm = 110 mm to ensure a safety level, that corresponds to current anthropometric data on the one hand and current safety awareness on the other. This is reflected by the considerations given in EN ISO 13857 (2008), where, for the safety of machinery, a safety distance of at least 120 mm is demanded. As the investigation shows, this corresponds to current anthropometric data and still leaves a desirable safety cushion.

Starting point and (Safety) Supplements:

Motivation	Values
Starting point: Largest index finger length (p99, male) of the ISO-populations given in the current ISO/TR 7250-2	approx. 90 mm
Supplement: Distribution data are so far available only from a few ISO member bodies	+10 mm
Supplement: Potential penetration depth of the index finger is larger than the index finger length measured acc. to ISO 7250-1:	+5 mm
Supplement: Fingernails may increase the index finger length:	+5 mm

Resulting proposal for the test finger length :

(90 + 10 + 5 + 5) mm $\geq$ 110 mm

The resulting length is significantly larger than the 99th percentile of the potential penetration depth of the index finger of the current population.

Figure 4. Proposal for the length of a contemporary test finger, derived from anthropometric and safety considerations

This is in contrast to the length of the common jointed test finger given in EN 61032 (1998), where a length of just 80 mm is demanded. There is a significant discrepancy to the current anthropometric data on the one hand and to the requirements in standards on machinery on the other. Although the intentions are comparable, it looks as if the length of the test finger has not been adjusted to the anthropometric changes and also the growing safety standard of the last decades.

A correction of the dimension and a unification of safety standards is a meaningful task. This is especially related to the test finger length. Again, basically positive is the diameter of 12 mm, which offers a high level of protection. Also basically positive is the tripartism of the common jointed test finger, which allows to take into account the mobility of the finger. The fact, that the test finger according to EN 61032 (1998) is also used for the IP-Code testing according to EN 60529 (2000), may be seen either as a challenge as well as an opportunity.

According to the investigation presented here, an adjustment of the test finger length to at least 110 mm seems to be necessary, representing the changes in anthropometric data but also the changes in safety and safety awareness during the past 50 years. As at least the IP Code 1XB is affected and in order to comply with a contemporary level of safety, without such an adjustment testing institutions using EN 60529 (2000) should interpret the reference "adequate clearance from hazardous parts" given in the standard in a rather wide range.

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