OPENING LECTURE

Standardization and Electrical Safety

Dr. John G. Leach

Consultant – Hi-Tech Fuses, Hickory, NC, USA, j.g.leach@ieee,org

Abstract

This is the opening day lecture at ICEFA 2011 on the subject of "Standardization and Electrical Safety". After a general introduction, on the purposes of standards and the author's background, a brief review of "safety" as it relates to fuses is attempted. This is followed by a discussion of the standards process, and some examples are given of current standards development that are intended to improve the application of fuses.

Keywords: e.g. electric fuse, fuse standards, fuse application.

1. Introduction

Electrical standards, related to fuses, have existed since the earliest days of fuse use. Standards are developed primarily for the direct benefit of two groups, manufactures and users (users being considered as those who purchase fuses, or who purchase equipment that includes fuses). However when the issue of "safety" is considered there is a much larger group that benefits, and that is everyone who uses electricity or is ever near electrical equipment. Few people do not fall into this category!

Fuse standards are written primarily by representatives of fuse manufacturers, with input from users. This is because, in general, the work is done by "volunteers", often persons supported by their employers or by manufacturer's organizations. Since manufacturers have the most to gain financially from the existence of standards, and manufacturers are generally the most knowledgeable concerning the practical aspects of fuse design and development, it is no surprise that they are the ones to primarily support standards making.

At the most basic level, a standard lays down the rules that apply to all products of a particular type - that is standardizing both testing and the product itself. An old myth is that standards inhibit innovation and restrain trade. In fact the opposite is true; without at least certain standards there would be chaos. The fact that standards change as often as they do is testament to the progress that occurs because of, rather than in spite of, standards. For fuses, in addition to the obvious advantages of standardizing such things as voltage and current ratings (and in some cases physical dimensions), the manufacturer also gains by having standards set some limits to the amount and types of testing required; without a standard, a user could specify any tests they wanted, whether or not relevant, which would make testing completely open ended. The user gains from fuse standards since they can be sure that any given product has received testing at least equal to that deemed necessary by a consensus of the most knowledgeable people in the field. Since few uses are sufficiently skilled to specify their own testing requirements, it relieves them of this burden. Perhaps somewhat surprisingly, it can be argued that limiting the scope of testing is actually beneficial to the user, since with no potential limit on testing, new products could be too expensive to develop; no manufacturer would undertake a development without a reasonably firm estimate of the testing costs, since they can be so high. This is particularly true in the case of high current interruption tests, where short-circuit testing can cost the equivalent of between about 5 000 to 50 000 US dollars a shift, depending on location and power requirements.

When issues of "safety" are considered, three general areas are relevant, and standards have a bearing on all three. The first is that the correct types of fuses should be chosen to provide appropriate protection when electrical failures occur, in order to minimize risk to life and property, and minimize the extent of the loss of electrical power. Standards can help here through application information of an "educational", or tutorial, type. The second area is that is that fuses must work correctly within their ratings, so that they do not add to the problems present when faults occur, or even worse cause a failure. Here standards help by providing standardized testing requirements that assist in ensuring a product has been designed to work properly in service. Thirdly, even a fuse that has been designed and tested correctly cannot provide protection if it has not been applied correctly (i.e. if it is the wrong type of fuse for the task, or the correct type but with the wrong ratings). Again standards can provide application information to educate the user in the correct choice of a fuse. Most fuse "failures" are as a result of misapplication.

Because the potential scope of the lecture's title is so large, of necessity coverage of only certain aspects of standards development and their significance will be attempted. However coverage will include discussion of standards development at both the National and International level, and some of the current developments taking place in International Electrotechnical Commission (IEC) High-Voltage (HV) fuse standards, all aimed at making the (electrical) world a safer place.

2. Background

The author's background is in the design and application of fuses of many types; initially experience centred on low-voltage fuses (that is with fuses having a voltage rating up to 1000 V ac and 1500 V dc) to be followed, for the last 33 years, by high-voltage fuses (over 1000 V ac). Consequently most of the comments in the lecture will relate directly to HV fuses. However many of the more general comments will relate to the other primary areas of fuse standards: low-voltage fuses and miniature fuses.

There is, perhaps, a general impression that a product that has been in widespread use for well over a hundred years (some would claim almost 150 years, or even 230 years![1]) is so mature, there should be little reason to change a fuse standard. In fact it is a cause of concern to some manufacturers and users that standards do change, often more frequently than they would like, and an attempt will be made to explain why this is so.

3. Standards and "safety"

Fuses are protective devices and, like all protection, their primary function is to act in the case of "something going wrong". Some failures may be caused by human error (e.g. it is virtually impossible to make all insulation so perfect that it will last forever) while others are the result of "natural" phenomena such as lightning, storms and earthquakes. Therefore, it is inevitable that some failures will occur. Many fuses are therefore designed to operate when all else has failed, and we seek to make them as well and reliable as possible. No manufacturer wants to create a product that will not work properly. However, a fundamental question is "how does one design testing to find out what might not work correctly in a product, if one does not know in advance what might not work correctly?" Fortunately with fuses we have over a hundred years of commercial (and standards) experience to head manufacturers in the right direction. Standards represent the collective wisdom of our fuse community. As particular applications became common, experience (sometimes a bad experience of course!) suggested areas that needed to be addressed in terms of standardized testing. This is testing required for a new design for a recognized application. For new applications, the situation is more complex, as appropriate testing may not be available in standards. This issue is somewhat addressed in the paper by Leach [2] at ICEFA 2003. New test requirements typically appear first in "regional" standards and only later find their way into IEC standards. More on this later.

A fundamental principle applied to most fuses is that of "type testing". The testing that may be conducted on every manufactured fuse is somewhat limited. The most important tests (interrupting tests) leaves the fuse unusable, so the method used is to thoroughly test a new design and then not deviate in any way from that design in manufacture. Any manufacturing changes that could affect a fuse's performance must then be addressed with additional testing.

System safety is therefore dependant on the correct testing of a fuse design followed by correct manufacturing of the device. The final aspect that is vital to "safety", however, is in the correct application of fuses. Demonstrating that a fuse will work perfectly under the conditions for which it was designed and tested certainly does not mean it will work correctly if it is subjected to conditions for which it was not intended!

Despite being a device intended to enhance the "safety" and functionality of power systems and equipment, it is unlikely that, today, there will be any reference to "safety" in the fuse standards and application guides. While "safe" has a variety of meanings, one of them is the protection of persons from harm. When the IEC HV fuse tutorial and application guide IEC 62655 [3] (see 6.) was first being written, suggested wording included such phrases as "safely interrupt". By this the writer meant interrupting current with the fuse intact and doing its job as was intended. However it is impossible for any HV fuse to "safely interrupt", if by "safely" we mean no one will suffer any harm. If the fault were caused by someone coming into contact with a live conductor for example, even a successful fuse operation is very unlikely to occur with no harm to the person being electrocuted. The phrase in the above example therefore ultimately became "correctly interrupt". Much care is now being exercised in writing standards to avoid any issues of liability, so safety aspects may be down-played to some extent (e.g. "the tests assist in ensuring that..." rather than "the tests ensure that..." We have to face the fact that excess electrical current through the human body is damaging, and this is the price we pay for a technology that enhances and improves our life in so many ways. However it cannot be argued that the general "safety" of our electrical systems is not enhanced by the correct use of fuses that have been tested to appropriate National and International standards. I use the term "correct use" advisedly, since, again, only when correctly used can fuses work successfully in a system. Therefore, better application advice is the next major step forward in IEC standards (see 6). Before discussing this important aspect of "safety", however, some general information on standards bodies and the standards process is in order.

4. Standards bodies and the standards process

Most countries have some form of standards body or bodies, responsible for writing or approving electrical standards. The way in which such standards are written, approved and enforced (or in many cases not enforced, since often standard compliance is voluntary) varies from country to country and even between fuse types in a given country. The subject is therefore too large and complex to be addressed in a brief lecture. Since specific examples will be given between IEC and IEEE HV fuse standards, a brief description of these two bodies and their process for developing and maintaining fuse standards will be given. The Institution of Electrical and Electronic Engineers (IEEE) is "the world's largest professional association for the advancement of technology" with over 400 000 members from more than 160 countries (with over 45% from outside the USA). The IEEE has a "Standards Association" (SA) within its structure and members pay a fee to belong to this group. HV fuse standards are developed within a subcommittee of the Power and Energy Society (PES) Switchgear Committee. The HV Fuses subcommittee and its working groups write and maintain HV fuse standards, primarily addressing North American practice (though it should be pointed out that "North American Practice" – a phrase also recognized in IEC standards – extends well beyond North America and in fact is common around the world, except in Europe). Standards developed by IEEE and other bodies are also recognized as "American National Standards" by the American National Standards Institute (ANSI).

IEC is also a world organization, but its "members" are individual country's National Committees. The National Committee for the USA, for example, is ANSI. The IEC Technical Committee (TC) for fuses is TC 32. It is divided into three subcommittees SC32A (high-voltage), SC32B (low-voltage) and SC32C (miniature). The TC rarely meets, while the subcommittees meet periodically (every few years) usually at main IEC plenary meetings. At such meetings, attendees represent their countries (one voting member per country). The actual work of writing and maintaining IEC standards is done primarily in Working Groups (WG) or Project Teams for new documents, and Maintenance Teams (MT) for existing documents. Members of these groups work as individuals (rather than as representatives of their countries), although such "experts" have to be nominated by their National Committees. After the WG/MT develop a document (a "Committee Draft" or CD) the document is circulated for comments from the National Committees. If there are many significant comments, additional CDs may be produced. When the document is essentially finished, at the "enquiry stage" a Committee Draft for Vote (CDV) is issued, and countries have to vote on the document. Providing sufficient affirmative votes are received (2/3), the document is essentially complete, although minor changes before a final vote (in the case of a standard) occurs with the circulation for vote of a Final Draft International Standard (FDIS). IEEE standards have a similar process, except that all document circulations outside the WG is in the form of a ballot. Here the balloting group is made up of interested parties. Anyone, anywhere in the world, who is an IEEE SA member can join a balloting group in which they have an interest, and any comments made to a ballot must be addressed. Even if the WG disagrees with a comment and rejects it, they must give a reason and recirculate the ballot and reason so that everyone can have the opportunity to change their vote. Only when this process is complete, and an affirmative vote of at least 75% has been achieved, can a standard be submitted to the IEEE Standards Board for approval.

There is a special relationship between the IEEE and IEC. Some IEEE documents are adopted by IEC and some are jointly developed. Such standards are termed "dual logo" standards. In addition, many IEEE and IEC working groups have members in common, so that coordination and cooperation is achieved. The author is one such person.

5. Standards development

The main problem for standards makers is to decide what applications have enough interest to enough people to warrant inclusion in a particular standard. As stated earlier, there is a natural disinclination to change standards more often than is absolutely necessary. However, while the pace of new fuse product introductions has inevitably slowed, as the field of fuse technology becomes more mature, new materials and new applications constantly demand that changes to standards be considered.

The process of introducing new requirement into existing standards is not an exact science. For example, there have been some devices that have appeared in the marketplace, and subsequently disappeared, without ever having testing specific to their requirements being included in any standard. Of course, there have also been other devices, at one time popular and included in, at least regional, standards that have declined and become obsolete and had their testing requirements removed (e.g. oil-fuse cutouts). The SF_6 fuse is a case of the former type of device. Similar in concept to the vacuum fuse, this used a short element between two massive contacts in a very small enclosure filled with SF_6 gas. It was similar to an expulsion fuse in performance, but more compact and with the advantage of no expulsion products. Although it was useful as a high current rating fuse suitable for encapsulation and use in insulated conductor systems, its cost and difficulty of manufacture led to its demise. While the expulsion fuse standard IEC 60282-2 [4] states that it can be used for any non-current limiting fuse (so that would include SF_6 and vacuum fuses), both devices remained as possible work items (PWI) with the IEC HV fuses subcommittee until relatively recently. Believing both devices to be no longer made (they are no longer made in Europe or North America), at the 2009 IEC SC32A meeting they were dropped as possible subjects for inclusion in IEC standards.

The question is therefore, "what is required for a new device or application (that requires additional testing) to be included in IEC standards?" Usually, the first requirement is that there be more than one manufacturer of the device. "Standardization" implies that several different devices should have common requirements. Secondly, sufficiently widespread use is needed to gain support from a number of countries' National Committees. Finally, sufficient "experts" willing to work on creating the necessary testing requirements need to be found. This is why there is more variety of device and testing requirements in National or regional standards where agreement for change is likely to be easier to get. For example, because of the concern with starting brush fires, Australia has the most comprehensive testing requirements for the exhaust products of a distribution fuse-cutout (expulsion fuse), while IEEE has testing requirements for liquid-submerged expulsion fuses, because they are widely used in North American practice.

National standards existed before IEC, and IEC represented a attempt to draw these national requirements into a common format and with common requirements. Obviously this is of particular use to developing countries who did not have their own standards prior to IEC. However, Leach [2] discusses in some detail the difficulties of getting agreement as to what should appear in an IEC standard. It was explained that international participation in IEC HV fuse activity is relatively weak and dominated by a few countries. While fuses are used in probably every country of the world, only 21 countries are "P" (participating) members, and 19 are "O" (observing) members of the IEC SC32A. Even worse, however, less than ten countries are regularly represented at IEC meetings at this time. IEC standards therefore tend to represent the "lowest common denominator", that is fuse types, applications, and their associated testing that the majority present at meetings can agree need to be addressed. This means that even quite widespread applications, that are not common in the majority of the relatively few countries represented in meetings, may not appear in IEC standards. In [2] there are some details of the attempts made to draw IEC and IEEE HV fuse standards closer together. It explains that great care must be exercised if fuses and techniques developed using a particular philosophy (e.g. North American methods that use fuses tested to IEEE) are employed in another country that has IEC standards as their norm, if the IEC standard does not recognize the additional testing required for such a fuse type and application.

Because of the limitations inherent in trying to write a "one size fits all" approach to standards, many countries adopt IEC standards but add their own "in country" requirements. In some cases this may be no more than a Annex giving additional relatively minor additional requirements (e.g. specifying some preferred time-current characteristics – of which there is little in IEC HV fuse standards). At the other extreme we find IEEE standards, which while following most of the IEC fuse requirements, uses a somewhat different format and includes special testing for several types of fuse not addressed in IEC standards (e.g. open-link, liquid-immersed, and enclosed cutouts). Despite these differences, IEEE are constantly trying to line up better with IEC, and the IEEE Fuse Subcommittee has a project in hand with this aim in mind. The special relationship between IEEE and IEC has been mentioned (4.). One area where the cooperation is somewhat less "official", but very real, is the development in SC 32A WG6 of a fuse tutorial and application guide [3]. Some details of this project will be given, because it illustrates a very positive direction both for IEEE and IEC cooperation and an important step forwards for HV fuse standards in general.

6. Development of IEC 62655 TR

IEC HV fuse standards presently have five active documents. Four of these (current-limiting fuses, expulsion fuses, motor circuit fuses and capacitor fuses) contain testing requirements and some application information. A fifth document, a technical report, contains application information for the selection of HV current-limiting fuses for transformer circuits. No single document contains application information for HV fuses, unlike the situation with LV fuses, which has IEC TR 61818 Application Guide for low-voltage fuses [5]. In addition to the lack of convenience of having a single reference document for applications, concern had been expressed in view of the gradual loss of expertise among users. This has occurred as economic conditions have forced fewer engineers to take responsibility for larger numbers of devices after the retirement of engineers whose primary responsibility had been fusing. Although some manufacturers produce their own application guides, the desire was expressed for an “official” guide that customers would know was unbiased and represented the consensus of fuse experts throughout the world.

About 20 years ago the necessity arose to introduce definitions and testing for “Full-Range” current-limiting fuses in both IEEE and IEC HV fuse standards. Unlike with IEC standards, all of the application information in IEEE fuse standards was gathered into one document, IEEE Std™ C37.48 [6]. An IEEE survey of fuse users at the time disclosed widespread confusion concerning the different types of HV fuse, and so in addition to introducing special Full-Range fuse testing, a tutorial was written to explain the basic construction, operation, classification and application of current-limiting fuses of all types. This document, IEEE Std™ C37.48.1 [7] included an extensive section on common applications and went well beyond the constraints of C37.48 (although there was some duplication of information).

In standards development of a few decades ago, writers were discouraged (by older participants) against making statements in standards that were “tutorial” in nature. The old way of writing standards was to give no more information than was absolutely necessary. Now while a precise and unambiguous style is vital for a good standard, minimizing commentary and explanations of why a test is being done does not guarantee clarity, but often has the reverse affect. Even today, it is not uncommon to discover testing requirements in standards written many years ago that are somewhat ambiguous. If the reader does not already know what was intended requirements may be difficult to understand (for obviously those who wrote them knew exactly what was intended, but often failed to convey such information in an unambiguous manner). There has therefore been a gradual recognition that our documents need to be made more “user friendly” (although some of the “old thinking” still exists and not necessarily from elderly engineers!)

With some inspiration from IEEE Std C37.48,1, and in a spirit of helping the user, it was decided by the IEC HV Fuses subcommittee SC 32A to embark on the production of a tutorial and application guide IEC 62655 TR. It was to go well beyond what we had done in IEEE, and was truly grand in its scope. It is instructive to read the “mandate” given to the Working Group 6 responsible for its production:

"Given the general decline in the number of engineers having knowledge of fuses and their applications, the following goals have been identified:

- to help prospective users and protection engineers understand the basics of fuse technology and applications involving fuses, and to enhance the usage of such fuses;

- to illustrate the particular and unique advantages of fuse protection for most service applications;

- to minimise possible misapplications of fuses which could lead to problems in the field;

- to list and describe the many types of fuse in use today and the International standards and test procedures that apply to them;

- to consolidate and enhance existing knowledge of fuse application."

The Working Group has therefore gathered all of the published HV fuses application information available including both IEC and IEEE standards and has produced a document in broadly two parts, the first covering more “tutorial aspects” – that is how both current-limiting and expulsion fuses work and their ratings and characteristics, and a second part – covering application details. In the second part, in addition to application considerations common to most if not all applications (e.g. current and voltage selection) there are separate sections for the most common applications (e.g. overhead lines, transformers, motors, capacitors, wind power generation, etc.). Since installation, operation, maintenance, replacement, and recycling are also addressed, this is a very comprehensive document (presently having about 120 pages). With the decision to cover many more applications than were covered in existing IEC documents the Report should have wide application (e.g. for transformer protection, the typically North American practice of combining expulsion and Back-Up fuses is covered in addition to the typically European practice of striker tripped switches and Back-Up fuses). It is hoped that this document, with relatively minor changes can be adopted as an IEEE/ANSI standard (primarily requiring changes in nomenclature – "melting" versus "pre-arcing" for example).

7. Other activities in IEC standards

In addition to the Tutorial/Application Guide, presently close to having a second Committee Draft (CD) issued, work is also occurring in MT7 on a revision of the standard "HV fuses for external protection of shunt capacitors", IEC 60549. The level of interest in capacitor fuses can be gauged by the fact that this standard was written in 1976 and has not been changed since. Although of limited interest, capacitor fuses are in quite widespread use and so it was felt by SC32A that a revision of this very old document was necessary. The first CD stage should be complete by the time of ICEFA and it will be interesting to see whether this draft revision has generated any significant comment.

MT3 continues to address issues with HV current-limiting fuses as they arise. The common North American practice of including current-limiting fuses in transformers is now spreading to Europe. In [2], there was discussion concerning the challenges that this can provide certain fuse designs, and the testing included in IEEE standards to address this. Some of this additional testing is now included in IEC, although with rather "weaker" requirements. For this application, however, all fuse designs need a more rigorous thermal cycling test to demonstrate the suitability of their sealing system for the higher temperatures to which they are exposed in transformers, compared to the typical European practice of fuses in oil-filled switchgear. Plans are therefore underway to include testing that is modelled on IEEE thermal cycling requirements for transformer applications. This testing has been in use for more than 30 years in the USA, and has produced excellent application experience.

Another area of interest to standards makers is non-ceramic insulators. There is a growing trend of polymer insulators being used for distribution fuse-cutouts. While standards have been established for composite line post insulators and suspension insulators, there are somewhat different conditions imposed on cutout insulators. Therefore for this application, IEC 60282-2 presently only requires that testing of composite insulators be by agreement between users and manufacturers. Work in the USA and Canada is seeking to redress this situation, but proposals for test methods have not been without controversy. When agreed test methods have finally been established in IEEE standards, it is likely that there will be interest in using them in IEC 60282-2.

8. Conclusions

The subject of standardization is vast; the issues involving safety are endless. But in summary, three things are needed to maximize "safety" when fuses are used as part of an overall protective scheme, all of which are addressed to a greater or lesser extent in fuse standards:

1) Firstly, an individual device needs to be designed and tested in a manner that demonstrates its ability to perform a particular function. Our fuse standards, both National and International, are a good starting point, but as pointed out in [2], no standard is a substitute for a knowledgeable manufacturer with integrity. Our standards have even begun to specifically acknowledge this. For example, if one looks at the "crossover testing" required for HV Full-Range fuses that use "dual elements", IEC 60282-1 recognizes that only the fuse manufacturer can specify the test currents needed to show that the fuse meets the "spirit" of the standard.
2) Secondly, a fuse must be used for an application for which it is suited and applied following the necessary application guidelines. While this might seem obvious, the IEEE survey discussed earlier showed that some users thought a Back-Up fuse can clear any current that causes it to melt! Misapplication of a Back-Up fuse could, potentially, be worse than no fuse at all (in an oil tank for example). It is primarily to address this second point that the project to produce the HV fuse Tutorial/Application Guide was launched.
3) Thirdly, the user must treat a fuse with appropriate care. In the IEC application information for high-voltage fuse-links, it is advised that fuse-links should be handled with at least the same degree of care as any other precision-made item of equipment (such as a relay). Careless handling, especially of CL fuses, can result in damage that may prevent a fuse from working properly and in particular from interrupting fault current correctly.

The large number of people who are engaged in the writing of standards should be commended. While in some ways a tedious and thankless task, our industry could not exist without carefully written standards. One area where the standard process could be improved is by having more participation from the users of our fuses. Attending standards meetings is both an excellent education, and also gives one the opportunity to help steer standards to be of more relevance to the product user. A large part of the actual work of writing standards is done by volunteers who are retired (as they tend to have enough time to do the work) or by working engineers but in their “spare” time. A debt of gratitude goes out to them all.

References

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[4] IEC 60282-2 2008, High Voltage Fuses – Part 2: Expulsion Fuses

[5] IEC TR 61818:2003 Application Guide for low-voltage fuses

[6] IEEE Std C37.48™-2005, IEEE Guide for Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

[7] IEEE Std C37.48.1™-2002, IEEE Guide for the Operation, Classification, Application, and Coordination of Current-limiting Fuses with Rated Voltages 1-38kV (ANSI).

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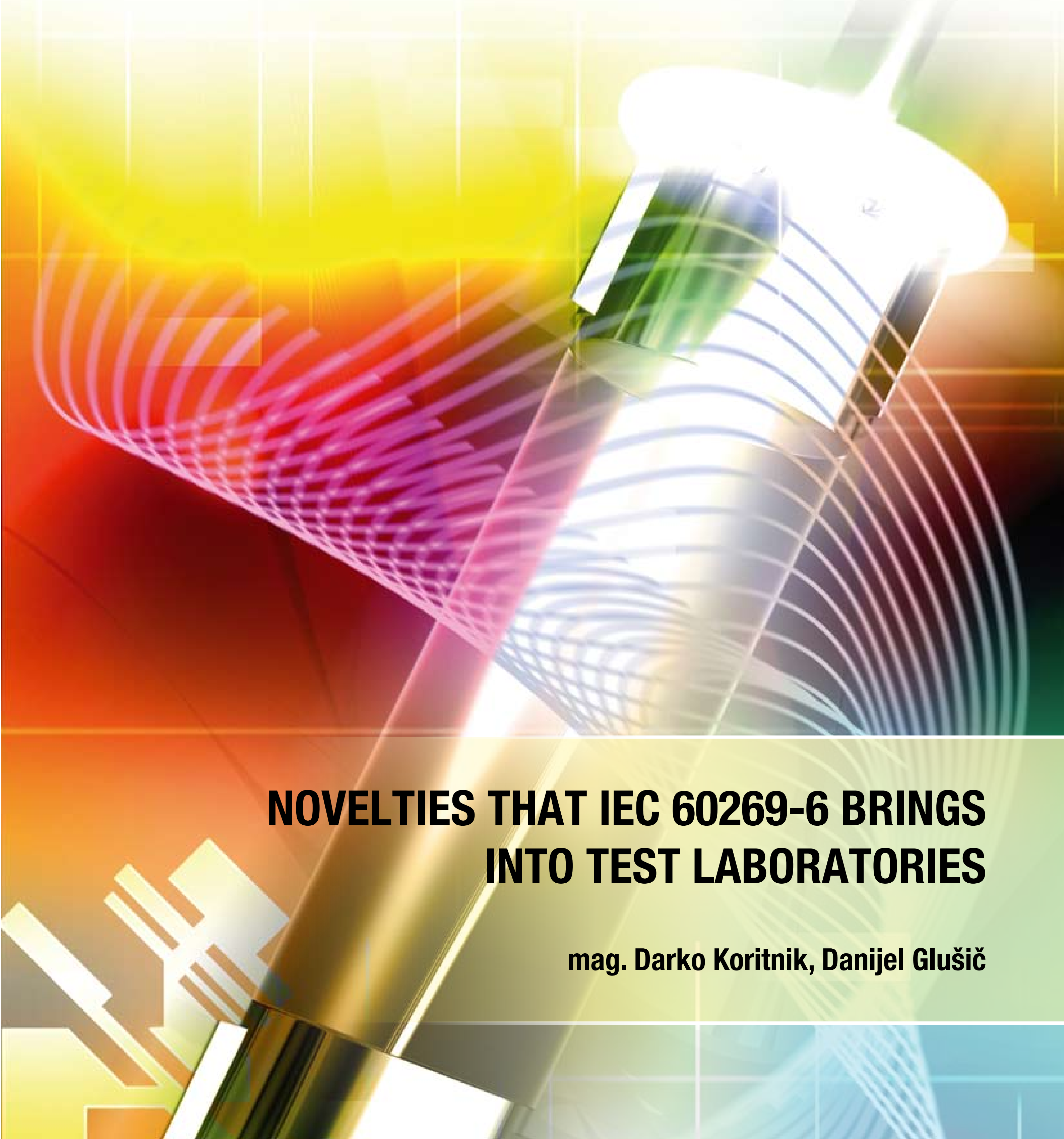

NOVELTIES THAT IEC 60269-6 BRINGS INTO TEST LABORATORIES

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