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Hans J. Kolitzus, IST Switzerland

Scrutiny of Advanced Artificial Athlete (AAA)

History of Artificial Athletes

Let me give you an outline of the development of the sports surface technology and the Artificial Athletes. There are already a number of Artificial Athletes available in China. Maybe it is interesting to hear the story at first hand.

The first synthetic sports surface for athletic tracks was installed in 1966 in St. Paul, Minnesota, by the 3M Company. Since the Olympic Games in Mexico, it was clear that from then on that only synthetic surfaces would be accepted for top level athletic events. The first artificial turf was installed around the same time in Houston, Texas, in the Astrodome arena by the Monsanto Company. The product and the manufacturing subsidiary were then named after this first installation site: AstroTurf. Both products were developed to a very high level right from the beginning. These products played a model role for further development until today although major modifications have been introduced since.

Synthetic sports surfaces were made possible by using polymeric materials which allowed design of surfaces according to the sportive needs. Synthetic surfaces were produced from PUR resins which could be cured at outdoor temperatures and could be modified in respect to their hardness. For artificial turf surfaces the development of UV stable soft Polyamide and later on Polyolefin (Polyethylene in particular) fibers was crucial.

The technological design of the products is the task of the manufacturers and is of proprietary nature. On the contrary, the users of sports surfaces have the task to control the products from a **performance** point of view. Up to the mid 1960's nearly no testing of sport surfaces was performed regarding their sportive performance.

> Remark: Performance is the behavior of products with respect to their usage, contrary to the technological specification and description. Young's modulus of elasticity or thickness are technological parameters, Vertical Deformation (VD) or Force Reduction (FR) are performance parameters since they reflect the behavior of product systems as used.

One of the first steps of performance testing was taken in the US to test artificial turf surfaces. They used and are still using a 9.1kg drop weight (equipped with an accelerometer) with a flat face (129cm^2). The maximum deceleration is called G_{max} as a multiple of g, the natural constant of gravity. G_{max} during the impact is an indicator of the surface's resilience. However, this parameter was not derived based on biomechanical considerations but a convention to compare resilience pragmatically. It could also be used on artificial turf surfaces only. This test is still in use and is standardized in ASTM F355 and ASTM F1936.

Activities of this kind started also in France and in the Netherlands: Laboratoire de Sols Sportives (later passed into ownership of Labosport) and the Netherlands Sport Federatie (NSF; today ISA-Sports). These labs also developed specific test procedures for synthetic and artificial turf surfaces.

Testing development became an international focus around the year 1985 when cooperation commenced among laboratories on an international level. A major factor in this process was the foundation of the ISSS (International Association of Sports Surface Science) in Switzerland in 1985.

The development of the Artificial Athlete was based on biomechanical studies, and this is how it happened.

In 1966, the German Sports Federation (DSB) awarded a program to develop test procedures for synthetic track surfaces to MPA, the Institute of Building Materials of the University of Stuttgart (Otto-Graf-Institute named after its founding director). All these activities resulted in the preparation of DIN standards (DIN = German Institute of Normalization): DIN 18035-6 "Synthetic Surfaces for Athletics Tracks" and DIN

18035-7 "Artificial Turf Surfaces" (beginning in the mid 1970’s and the mid 1980’s respectively).

> **Remark:** these standards were in a certain respect role models for later international standardization leading up to the respective EN standards. Unfortunately, the DIN changed nature in the 1990’s and currently follows merely economized working rules: they are interested in the publication of as many documents as possible in order to sell them regardless of the quality and objectivity of their contents. Nowadays, there is also much confusion with DIN documents since DIN publishes aside of regular standards additional documents which are termed DIN Specifications (DIN SPEC). They have the same number as the regular standard, but don’t have official status: DIN 18035-7 versus DIN SPEC 18035-7. To its discredit, the DIN SPEC 18035-7 has been found to be a disaster. It had to be withdrawn by intervention of the European Commission due to violation of non compliance with international trade rules. It also emerged that some technical specifications were outside of reasonable technology.
> The answer of the ISSS was the preparation of the "ISSS Alternative Specification Artificial Turf Surfaces".

The Protection Function of sports surfaces was of major concern right from the beginning. It was assumed that this function was mainly constituted by the resiliency of the surfaces. However, there was no dynamic test procedure available at that time, neither for lab testing nor for testing in the field. As a preparation for the development of a dynamic test which simulated real athletes’ movement forces, a run-up track with a semi-synthetic surface was installed with a built-in biomechanical platform. Athletes were tested when performing various sports movements (long distance, short distance, jumping). It was found that all records showed predominantly sinusoidal shapes as their main part: see slides.

This information from a two-dimensional movement was translated into a one-dimensional test apparatus which produced similar sinusoidal actions/reactions on the surfaces. The Artificial Athlete Stuttgart (AA Stuttgart) was born. This development was reported in a publication of the Federal Institute of Sports Science available in German, English, and French).

The AA Stuttgart consists of a drop weight which is released for free fall onto a soft spring. The impact is transferred through a load cell onto a flat test foot of 70mm diameter. Simultaneously, the deformation of the test foot is recorded. Thus, with the maximum force during the impact and the maximum deformation the so-called Standard Deformation (StD) in [mm] is determined (today this parameter is denoted Vertical Deformation VD). The vertical deformation StD simulates the deformation of the surface under a dynamic load of 1500 N (twice the body mass of typical athletes = dynamic factor of 2). The anticipated body movement is the one of short distance runners. A surface is regarded the softer the higher the StD. The Artificial Athlete Stuttgart can be and is used on all types of sports surfaces.

In the mid 1970's, another parameter was introduced: Force Reduction. This parameter shows the reaction of a surface under the nearly un-damped impacts of athletes which occur from unexpected falls. For this, the similar type of test apparatus is used, but the spring is much stiffer: its name became Artificial Athlete Berlin (AA Berlin). The device is used on rigid concrete bases to determine the maximum force $F_{max\ concrete}$ which is 6'600 to 6'700 N. On a resilient sports surface the maximum force $F_{max\ sportsurface}$ varies between 2'000 N and 500 N according to the degree of resilience of the surface. The Force Reduction FR is calculated as:

$$FR\ [\%] = [(F_{max\ sportsurface}/F_{max\ concrete}) - 1] \times 100$$

Thus, FR may vary between 25 and 70% (FR on concrete is 0%). The effect of Force Reduction can be felt at the back of your head when you suddenly drop your body with straight spine from your toes to your heels. A hard surface will cause an uncomfortable shock. The advantage of this test is that only one parameter had to be recorded, namely only force and no deformation, which makes the testing easier. The FR parameter describes the reaction of the surface to an almost un-damped impact of a body. Concrete has a FR of 0%, whereas good sports surfaces have minimum of 35% (athletics tracks) and minimum of 60% (artificial turf) respectively.

In the mid 1980’s, the AA Stuttgart and the AA Berlin were designed in a way that they are using the same principle mechanical structure with just a few modifications:

		AA Stuttgart	AA Berlin
Drop weight	[kg]	20 (50)*)	20
Spring number	[N/mm^2]	40 (50)*)	2000
Drop height	[mm]	125 (30)*)	55

*) original values

This configuration is still used today in the standards EN 14808 and EN 14809.

Round Robins were carried out with both test procedures. The most recent RR (ISSS RR 2012) has been reported by Dennis Frank earlier today. He also stressed the general accuracy when measurements on the same sample are compared with those of other labs (Comparability). This has always to be kept in mind when regarding test results and assessing products.

The Advanced Artificial Athlete AAA

To make testing of surface resilience even easier, the Advanced Artificial Athlete has been developed. As far as I can see it was a combined effort of Labosport France and ISA-Sports to gain the determination of

- deformation VD,
- force reduction FR and
- energy restitution ER

with one signal only: the acceleration-time response of the drop weight during the impact.

The first description of the test was published in a FIFA document (2008). Instead of the force sensor and the deformation sensors an acceleration sensor (accelerometer) is attached to the top of the drop weight. From the acceleration-time signal the 3 parameters are calculated by single and double integration respectively. Unfortunately, the test was given in general terms only (formulas). Thus, for real testing the actual evaluation algorithm had to be developed and scrutinized.

Remark: IST is providing attachments to existing AAs Stuttgart / Berlin together with the (transparent) evaluation program. Thus, the existing Artificial Athletes can still be used.

Different from the AA Stuttgart and the AA Berlin, the accelerometer measurements and their derivations cannot be determined and scrutinized directly. The accelerometer may be calibrated, but there remains the question of how to check the performance of the integration algorithm? In order to find out whether the devices designed by the various labs produced comparable results, comparison tests were performed within the FIFA RR events in Paris, Valencia and Bergamo. After many years of frustrating efforts an acceptable degree of <u>compliance</u> between the labs has been achieved.

However, this type of checking proves practical compliance of certain labs only. What is going to happen if all labs are committing the same systematic error? In addition, most labs and suppliers of AAAs do not publish their individual evaluation algorithm. Thus, if you are going to buy a AAA you will get a "Black Box". Such a measuring situation is not satisfactory for serious testing. Up to now no proposal is available how to scrutinize the evaluation of the data acquisition part of the test.

Before the solution to this problem is described, let us go through some details of the test procedure. Our colleague, Alastair Cox from Labosport UK has delivered a perfect summary of the test at a Zürich Meeting in February this year. I have adopted a few of his slides in my presentation. I also want to point to Gert-Jan Kieft's presentation on the same subject held at the ISSS Conference in Paris in 2010.

Solution of Problem

The objective is to prove the correctness of the AAA measurements/results physically and independently. This can be performed in two ways:

1. Tests with the AAA on a concrete floor: ideally the FR parameter must reveal 0%, the VD parameter 0.0mm.

2. Tests on an ISSS Reference Unit/Norm. These reference units – originally developed by SKZ Würzburg – are mechanical devices with an almost perfect linear force-deformation characteristic. Ideally, there should be no difference between FR(AA) and FR(AAA) and also between VD(AA) and VD(AAA1500)[1] .

When comparing the VDs of AAA and AA Stuttgart, it is necessary to take into account that the AA Stuttgart is referred to a maximum force of 1500 N while the deformation VD(AAA) is produced by a much higher maximum force which produces a higher deformation. In order to compare deformation determined with the AAA and the AA Stuttgart, the VD(AAA) must be reduced to a maximum force of 1’500 N. The reduced value is denoted VD(AAA1500).

However, we have still to keep in mind that VD(AAA1500) does not reflect the same physical entity as VD(AA) on real sports surfaces since these have marked visco-elastic deformation characteristics. Therefore, the speed and the magnitude of the impact have a considerable effect. This can be seen when regarding the results of practical correlation studies on real artificial turf pitches.

But let us first regard the test results performed by IST on concrete and Reference Norms.

Tests with the AAA on **concrete** revealed an apparent

- FR value of 0% (absolute).
- VD(AAA) = 0.29mm
  VD(AAA1500) = 0.06mm.
- The Energy Restitution ER is about 95%. A more precise result with ER on concrete is not possible due to the physical condition of the system.

Tests with the AAA and the AAs on the **ISSS reference unit** revealed

- FR(AAA) = 38.1%   VD(AAA) = 3.28 mm; VD(AAA1500) = 1.18mm
- FR(AA)   = 39.0%   VD(AA) = 1.29mm

[1] VD(AAA1500) means VD(AAA) referred to a maximum force of 1500N

The results show a difference of 1% in FR and 0.1mm in VD(1500). The error in FR seems to be in the range of 2%, in VD(1500) in the range of 0.1mm. This result represents the general function of the AAA and AAs.

Arnoud Louveau and Eric Harrison performed repeated comparison tests with an AAA, an AA Berlin and an AA Stuttgart on various turf pitches. The information gained in this 2011 FIFA study reveals that FR(AA) is statistically slightly lower than FR (AAA ;) (mean -0.8%; range +3 until -4%), whereas VD(AAA) is statistically larger than VD(AA) (mean +1.6mm; range 1.0 until 2.2mm). Scattering of the individual readings is rather similar between FR (AAA) and FR(AA). Scattering of individual readings is statistically somehow larger with VD(AA) than with VD (AAA;).

The Energy Restitution ER of artificial turf surfaces ranges between 35 and 45%, whereas natural turf surfaces range between 20 and 40% in summer.

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