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PMT PREMIUM MOUNTING TECHNOLOGIES

The caterpillar effect

The solar industry is still debating the extent to which this problem, whereby temperature-related expansions and contractions cause an installed system to move gradually across a rooftop, actually occurs in flat-roof PV systems, and what a practical remedy might look like.

For half the days in April, Peter Grass had to dress warmly. Every morning and evening for four weeks, the Managing Director of Premium Mounting Technologies (PMT) walked into the new 40 foot container he had set up on the company grounds. He took readings, and switched the climate in the container from summer to winter and back again. "We set the container to -30, 0, and +30°C every 12 hours," he says. He did this to measure how his PMT Evolution flat-roof mounting system and the PMT Flat Direct roof-parallel system behave when subjected to alternating hot and cold temperatures, just as they are in real-world conditions but on a somewhat accelerated cycle, so that the effects become visible more quickly.

"You could hang a small car from these connections."

The industry has known about the problem this could cause for a year and a half, and yet, Grass has seen little more than just talk. The industry has been aware of the problem for a year and a half, but that it's largely talk over action, Grass believes. He wanted to finally get some clarity about how his system behaved on a slightly inclined roof, as the mountings expand and contract with fluctuations in temperature. In theory, each fluctuation causes the system to inch its way, like a caterpillar, a few millimeters closer to the abyss.

His reason for taking action was an inquiry from a large corporate group with numerous locations throughout Europe. It had already installed PV plants with systems from another manufacturer and, after some installations had shifted, it feared for its rooftops.

The caterpillar effect is also an issue in the construction division of the German trade association BSW Solar. Its members, BayWa r.e. Solar Energy Systems (SES), Goldbeck Solar, IBC Solar, Mounting Systems, PMT, and Schletter are discussing solutions for fixing arrays in position, says Martin Schäfer, Deputy Working Group Leader at BSW and Product Manager for mounting systems at Baywa r.e. SES: "We are working on an information sheet."

Photo: PMT

PMT CEO Peter Grass in front of the climate container at the company's facility.

When rules were introduced in Europe stipulating a minimum pitch of two degrees for flat roofs, it became clear that this issue was not going away. This means that all new roofs will have some degree of pitch.

Like a hanging car?

"We've never seen a problem with the caterpillar effect," says Peter Grass, "but now the customer has asked us to officially certify a large number of roofs with a 3.5 degree pitch." In theory, you could keep the system in place by simply attaching it to a fixing point in the roof, but the customer did not want more than ten connection points. If you work out the effective forces based on the theory, these connections would have to be designed so that each of them could withstand seven kilonewtons – meaning you could hang a small car from it. Such strong anchors are extremely complex, since such a force can usually not be directed into the roof. "I have seen designs in which pipes

The brief

Flat roofs with a pitch of just 1° can already result in movement of the solar array, due to the caterpillar effect. Temperature fluctuations cause the mounting system, rails etc. to expand or contract.

The position of the mounting structure can be secured using ballasting and other anchors, however theoretical calculations have shown that such anchors have to be substantial in size.

Actual measurements have now shown that the theory is overestimating the forces, which is why simpler anchors suffice.

the size of an arm pass down to the supporting structure" says Grass. The PV system then has to be designed around possible anchor points in the roof. He could not believe that this was the solution, "despite the fact that we have never seen any movement in an array!"

That is why Grass started measuring. He had the test setup monitored and evaluated by Körnschild Engineering Office. In the container he had a 1.73 meter wide test roof built with a 7.5 degree pitch. He then installed the PMT Evolution mounting system with two parallel rails. In the direction of the roof pitch, the system was 8.6 meters long. He fixed one of the two rails, while the other remained free, in order to measure its movement, and installed a newton meter at the anchor to measure the force at that point.

If an 8.6 meter long aluminum rail is heated from -30 to +30°C, its length theoretically changes by 6.5 mm, due to thermal expansion. Based on this consideration, it follows that in this case a compressive force of 26 kilonewtons would be necessary to compress the rail by the same 6.5 millimeters. In theory, a compressive force is limited by the static friction of the rail against the building protection mat and on the roof. When the force on the connection surpasses some 1.4 kilonewtons the system begins to move, which can lead to the caterpillar effect. Only when the compressive force exceeds the force with which the system adheres to the roof by friction does the system start to move and the caterpillar effect occur. In theory, if the system is secured via a connection, this force has to be counteracted by the connection, plus a safety margin.

> "Due to the spring effect of the connections, the expansion is a factor of five less than predicted."

Actual forces

Measurements quickly refuted this theory. The first surprise was that the rail only expanded by 1.5 millimeters. The second surprise was that a force of only 0.25 kilonewtons occurred where the test system was anchored in the climate container. If the required safety margin is added, the connection would only have to absorb 0.4 kilonewtons, or around one sixth of the initially estimated force. Since there are many influencing factors, Grass ran tests on numerous setups during the four-week experiment: with heavy ballast, with little ballast, with low friction Teflon-coated base rails, and with systems in east-west and north-south orientations. Consistently, the results demonstrated that the actual force on the connection was less than calculated according to the theoretical assumptions. Even the right rail, which was not anchored to the roof, never moved.

Photo: PMT

Layout of the PMT climate container. The left rail is connected to the test roof via a force measurement device. The right rail is not connected. The test is designed to show whether the right rail is moving and how much force is required on the left rail to suppress the movement.

Grass explains the result by pointing out that the system is flexible. The rails are constructed from several 1.88-meter-long segments with click connections. Due to the spring effect of the connections, the expansion is a factor of five less than predicted. In addition, the 11 mm thick polyethylene protective mat, which is glued to the system prior to delivery, can absorb part of the movement. "This protective mat has a higher elasticity than the conventional stiff building protection mat," he says. He introduced it about two and a half years ago. "It stays in the same position even if the rail on top of it moves 1.5 millimeters."

This, Grass believes, should put minds at ease and eliminate the need for fixing the array to the roof. But the situation is not quite that simple. "The wind load itself, blowing effects of the roof membrane, or strong vibrations in the building can accelerate the caterpillar effect," notes Grass. These effects are difficult to measure, so he recommends anchor points under certain conditions. Systems can be installed on roofs with pitches of up to 2.5 degrees without the need for any fixing system.

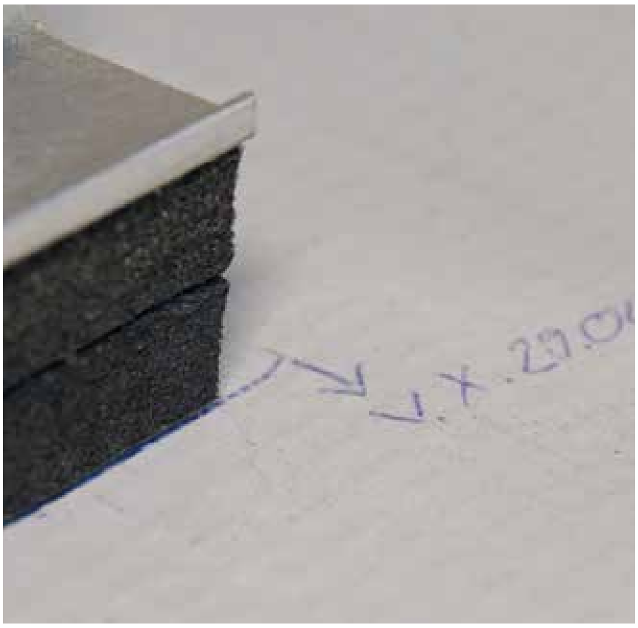
Photo: PMT

The measured forces were less than theoretically predicted. Peter Grass chalks that up in part to the flexibility of the connections of the click system.

"It may well be sensible to connect systems with springs."

For roofs with a pitch of 2.5 to 5 degrees, he recommends fixing hardware which he designed based on sample static loads representing the worst case. Since the test showed that actual incident forces are lower than previously feared, the connection to the roof can be made using a standardized component without the complicated step of opening up the roof. This is done by sinking self-tapping screws from above through the insulation into the corrugated sheet metal roof below and then sealing it with generously overlapping layers. "Like the PMT mounting system, the anchor point itself is approved by building authorities," says Grass. He is pleased to have found a solution that enables a skilled installer to fix the array to the roof and can be used flexibly on a variety of roofs without extensive static testing. For pitch angles of five degrees or more, he would conduct a detailed analysis of both the mounting system and the roof. In any case, customers are satisfied with his conclusions and he now has several dozen orders.

Photo: PMT



This rail did not move downward; it was not connected.

Trials at Baywa r.e.

Martin Schäfer of Baywa r.e. SES also initiated a field test at an actual plant this winter. Via four anchor points in the roof, he connected a 100 kW system on a roof with a pitch of 3.5 degrees.

To determine the dimensions of the fixing elements, Schäfer now primarily wants to determine the force acting on the fixing points in response to temperature fluctuations.

To do this, he connected eight cables via force gauges to the four connection points, and pre-tensioned them at different forces, from 5 to 15 kilograms. At the end of May, after seven and a half months of testing, the force values were read again, in addition to the minimum and maximum forces occurring during the period. The maximum force was insignificant at all of the connections, regardless of the degree of pre-tensioning – perhaps just a few kilograms higher than the preset tension.

Martin Schäfer inferred from this that no significant additional forces were involved. This is not the only reason that Schäfer doubts the accuracy of the theoretical calculation, which is based on the tensile force of thermal expansion. He has his own theory: As long as the static friction is greater than the compressive force resulting from temperature effects, no additional force is applied to the fixing point. If the static friction is exceeded, the system can move if not held down, according to his estimation. In that case, the only forces that occur are those which the system has on the inclined roof plane due to its weight, as if the array were on rollers. Only at the transition – the exact point at which the static friction is overcome – could maximum forces at the level of the compressive force occur. "These were compensated for by the springs of the tension gauges used to connect the systems," he says. With this in mind, it may well be a sensible solution in the future to connect systems with springs. Systems can also be left to "float" if the temperature-induced expansion in the direction of the roof ridge becomes too great. It is therefore also essential to pay attention to the length of the continuous rails in that direction.

Always anchor points?

Calculated in this way, Schäfer arrives at similar dimensions for the fixing system as Peter Grass. Despite the positive test results, Schäfer recommends that all systems be connected to the roof. "In my view, based on the theoretical model, the roof pitch is not decisive for whether the system will move, but only how fast it will move," he says. At the same time, he is aware that the extra effort of fixing arrays to the roof is one that nobody is keen to make.

It is also important to be aware that a shifting array is not immediately noticeable, as the effects can also be small. "They are often only discovered when leaks occur in the roof seal," says Schäfer. The mounting rails rub against the roof projections, the skylight, or ventilation pipes.

The important thing, says Schäfer, is that the fixing system for the PV array is not attached to the guardrail. If such restraints are installed additionally to hold the array in position, they should be designed for a fall load of six kilonewtons, but deform at a horizontal load of 0.5 kilonewtons (see photo above). "There is a danger that the roof seal could be stressed," says Schäfer. He wants to play it safe and offer solutions with a higher reserve. When planning systems for new buildings, he advises that there should be two kilonewton stops on the roof ridge every 10 meters.

Photo: Baywa r.e.

Such connections can protect against the caterpillar effect. However, the question is how they should be dimensioned. The product in the picture can withstand up to six kilonewtons, but it undergoes deformation at 0.5 kilonewtons.

Photo: PMT

In the climate container, the experts also set up east-west systems.

Module arrays of the same weight resting on a gable roof can be coupled together for mutual support, eliminating the need to secure them to the roof.

The question of when connections are needed is still open, at least until BSW-Solar issues its new recommendations.

There is another discussion brewing in the industry. The flat-roof regulations contain a passage stating that directing horizontal loads into the roof skin is not authorized, potentially giving roof membrane manufacturers recourse to appeal to the regulation. Peter Grass of PMT believes that the jury is still out on this issue

New publications would help to further develop the regulations, he believes. If the presumed roughness of the roof skin means that the horizontal wind load can be as high as the horizontal force normally applied by a photovoltaic system, the PV system cannot be the problem.

Grass proposes inclusion in the Flat Roofs Directive the principle that roofs must be built to accommodate increasingly frequent use, so that PV systems can be installed on them.

Michael Fuhs

A longer version of this article originally appeared in pv magazine August 2018 issue. For this edition new images have been added.

National technical approval for the complete system

PMT acquired national technical approval for its PMT EVOlution flat roof mounting system some time ago. What is unusual about this is that the approval applies not only to the components but to the system as a whole. According to CEO Peter Grass, this is unique in the industry. In an interview, he explains why he sees this approval as a major advantage.

pv magazine: There is no prohibition against installing mounting systems without a technical approval. So, what is the point of having one anyway?

Peter Grass: It's like driving without a driver's license or building a house without a building permit. You can do it; just don't get caught, because then you will face the consequences.

What liability does installer bear, and what about the client?

In principle, clients are responsible for their building's structural stability, fire protection and so on. They entrust installers with fulfilling these obligations, and the latter therefore have a duty to provide verification that they have done so. Foregoing a national technical approval opens up the possibility of incurring insurance, criminal, civil and statutory consequences. In the best case, this will only be expensive – in the worst case, the whole plant would have to be dismantled.

What did you do differently from other manufacturers?

We analyzed, tested and approved all of the individual connections in the system and obtained approvals for them. As a result, the item approved by the building authorities is an aerodynamic flat roof mounting system in its entirety and not this or that connector or component.

Not all parts require technical approval by the building authorities. When do parts require approval and what types normally require it?

Aerodynamic flat roof systems are so-called non-regulated construction products. Thus, the entire product is subject to the obligation for technical approval in individual cases, either the national technical approval or the acquisition of a national technical test certificate. This is always the case when the metal structure is verified by testing, when plastic parts are used, or when the system is bonded with adhesive. The first case in particular will affect 99 percent of all contemporary support-structure systems.

So, you're saying that for any system, even those with metal structures, you can't actually calculate the structural analysis, but rather you have to verify it with tests? And this, in turn, requires all of these systems to obtain a national technical approval for the entire system?

For cost-efficiency reasons, the component cross-sections of aerodynamic flat roof systems have become increasingly thin-walled and elaborate. These very slender and complex components and their connections can no longer be verified with the usual design methods according to an applicable standard; DIN EN 1999-1-1, for instance, for aluminium structures; if so, it can only be done with very costly and impractical results. Verification tests are therefore the preferred method, and this necessarily means that official approval is required by the supervisory authorities.

> **"Verification tests are the preferred method"**

This means that with your system you now have the advantage that customers no longer have to worry about whether the manufacturer really has the approvals for all of the necessary components because you have a document with a seal on it for the entire system. Right?

That's right! We provide legal security right from the start and can provide unqualified proof of this through our full system approval.

Why don't other companies do this?

The process of obtaining technical approval for an entire system is expensive, time-consuming, requires the right exper-

Photo: PMT

These components would be part of the certification.

tise, and it sets strict limits on product modifications, internal and external quality controls and so on. I think this spooks a lot of manufacturers.

What about the stability of the systems on the roof; things like the connection between frictional force and the application of force through ballasting? Is this also part of the national technical approval?

The ballast that holds the structure in position is not part of the approval – according to the original text. The problem arises one step earlier. Unfortunately, our proposal to incorporate our studies, trials and evaluations into the approval was not followed. Yet it was precisely the defined testing of the actual load influencing areas attained in the system in direct correlation with the influencing zones of the wind tunnel tests that was the decisive factor in determining the ballast. A product approval should not stop right at the point where the actual intended use begins. One possible way for the industry itself to give clout to these minimum technical requirements could be a reference paper from BSW-Solar. This could take on a normative character and perhaps at some point be incorporated into the DIBt testing requirements.

What about European ETA approval: wouldn't it make more sense to obtain that? Is it easier or more difficult to get?

The ETA, like all of the other processes in the European Union, requires a lot of patience. To get a product approved for which a harmonised European standard (hEN) or at least a European assessment document (EAD) already exists, the effort required to obtain approval is still in the acceptable range. For aluminum aerodynamic photovoltaic flat-roof systems, however, neither a standard, nor an assessment exists yet, and that makes the process very time-consuming and costly. First of all, the EAD has to be generated, reviewed and evaluated by all of the Member States; then, they have to reach a consensus and, finally, it has to be confirmed by an EU Review Commission. Only then can the actual approval and the ETA procedure begin. The subsequent translation into all of the national languages, the comment and waiting periods due to deadlines for appeals and comments then take at least as long as the preceding steps.

Ultimately, the advantage would be a CE marking and a product that can be used without restriction throughout Europe, but the ETA has a more of a descriptive character. The technical depth and meaningfulness with regard to performance is actually inferior to that of the German national technical approval, which casts some doubt on the process in terms of creating safer products. Nevertheless, we are considering the application for an ETA and hope that other manufacturers will follow suit. A number of the individual steps could then be initiated and processed jointly and would not be the sole burden of the first applicant.

The interview was conducted by Michael Fuhs.
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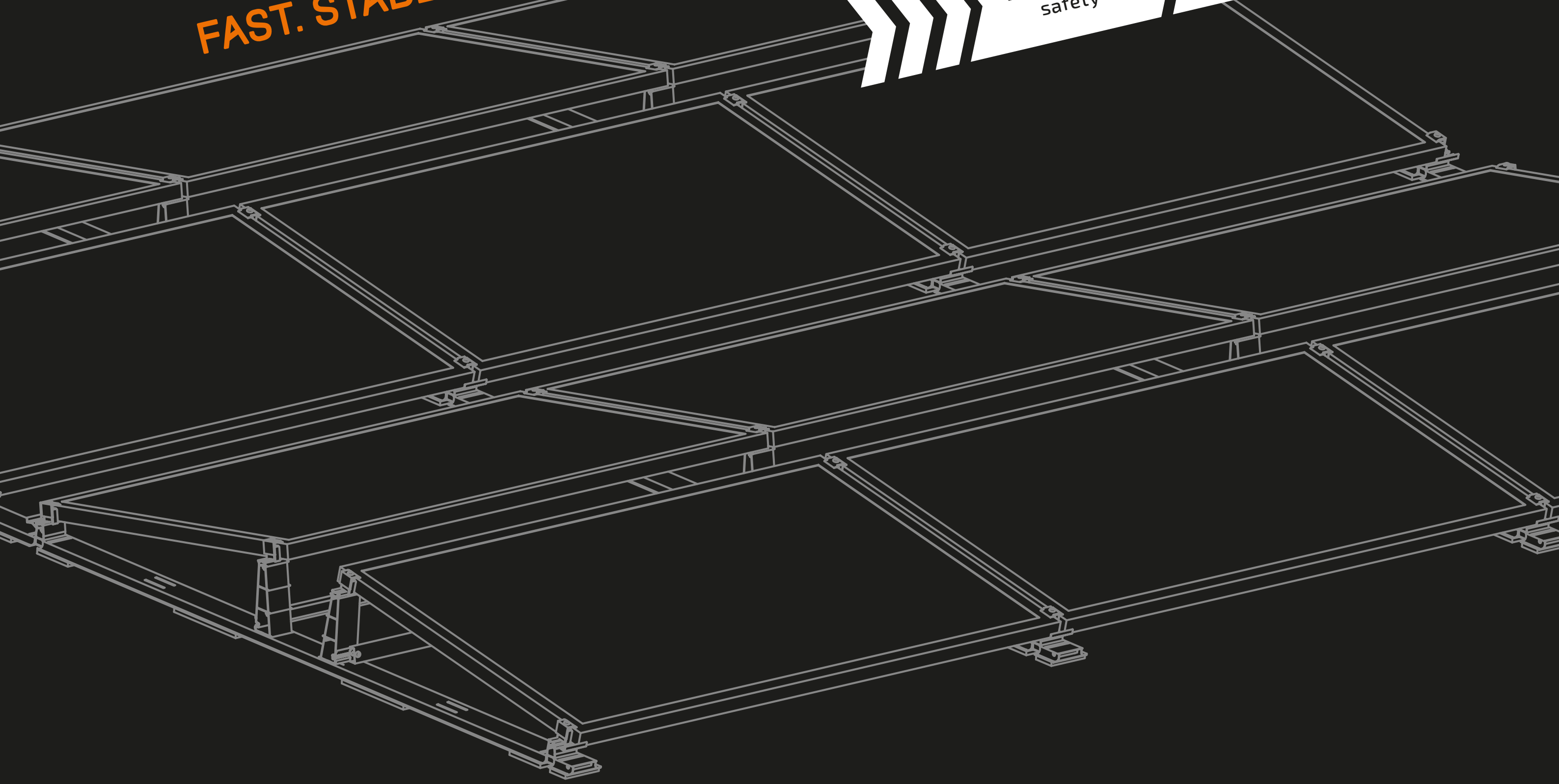

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