

CONSTRUCTION OF TWO PRECAST POWER UNITS IN UHPFRC

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Abstract

The project TOSA [1] proposes a new technology for urban mobility. It provides energy to electrical buses in another way than it is done for trolley buses today. One of their main disadvantages is the need to install aerial contact lines.

Instead of using contact lines, TOSA buses will recharge their internal power supplies at approximately every third stop. For charging, they will lift up their pantograph during a stop and connect for 15 seconds to an overhead “Flash” charging unit.

Two of those units have been constructed to test the technology on a prototype line in Geneva. Their design and construction in UHPFRC will be described in this paper.

Résumé

Le projet TOSA [1] propose une technologie nouvelle pour la mobilité urbaine. L'énergie électrique pour les bus est transmise par un système dit “Flash” tous les 3-5 stations. Ce système élimine les traditionnelles lignes de contact.

Deux stations test de chargement sont en cours de réalisation, afin de tester cette technologie sur une ligne prototype à Genève. Dans ce cadre, le BFUP a été choisi comme matériau pour la construction des potences de recharge.

1. INTRODUCTION

The TOSA¹ project group, formed by the Geneva public transport system (TPG), the Office for the promotion of Industries and Technologies (OPI), the Industrial Services of Geneva (SIG) and ABB Séchéron asked hepia to design the “Flash” charging units. These charging units are the most visible part of “TOSA”.

This task has been integrated into the student's project work during the summer semester 2012. One project has been chosen to be realized for the TOSA prototype line which is planned to operate between Geneva Cointrin airport and the Palexpo exhibition ground by may 2013.

¹ TOSA : Trolleybus Optimisation Système Alimentation

For this purpose, the initial design had to be developed further and analyzed from a structural engineering point of view. Two main aspects conditioned design decisions of the power unit:

- It should be a precast unit, which can rapidly be installed
- The unit should be as lightweight as possible, because one installation place did not support high loads. Other potential future installation places are likely to have the same issues.

It was decided to use UHPFRC for several reasons:

- Dead load is reduced by a factor of 2-3 compared to an execution in conventional concrete, since shell thickness of the element is reduced by the same factor.
- The increased tensile (flexural) strength with respect to a conventional concrete. The present application employs a structure which is mainly solicited by bending moments and relatively low tensile stresses. It was considered to use UHPFRC as the unique material without any supplementary reinforcement bars.
- The high quality, ceramic-like surface of UHPFRC, with its good resistance to environmental influences is attractive from an architectural point of view.

The prototype installation for the TOSA project required two power units, one to be installed at the airport train station of Geneva Cointrin (Unit 1), the other one to be placed next to Geneva's Palexpo exhibition ground (Unit 2).

Unit 1 at Cointrin has a particular design. It needed to be mobile, since it had to be temporarily installed for a commissioning at the production ground of the supplier of the charging equipment. After commissioning, it was transported and installed at its final destination, the airport. Additionally, it should be possible to install it on a flat ground without being connected to a foundation. These issues have been solved by adding a base with a counterweight to stabilize the unit (Fig. 1).

The counterweight is used to offer a seating possibility for commuters. Unit 1 weighs 5.5 t and is 4.2 m high. The counterweight at the basis has got an average length of 2.3 m and the overhead cantilever where the electricity should be installed an average length of 1.8 m.

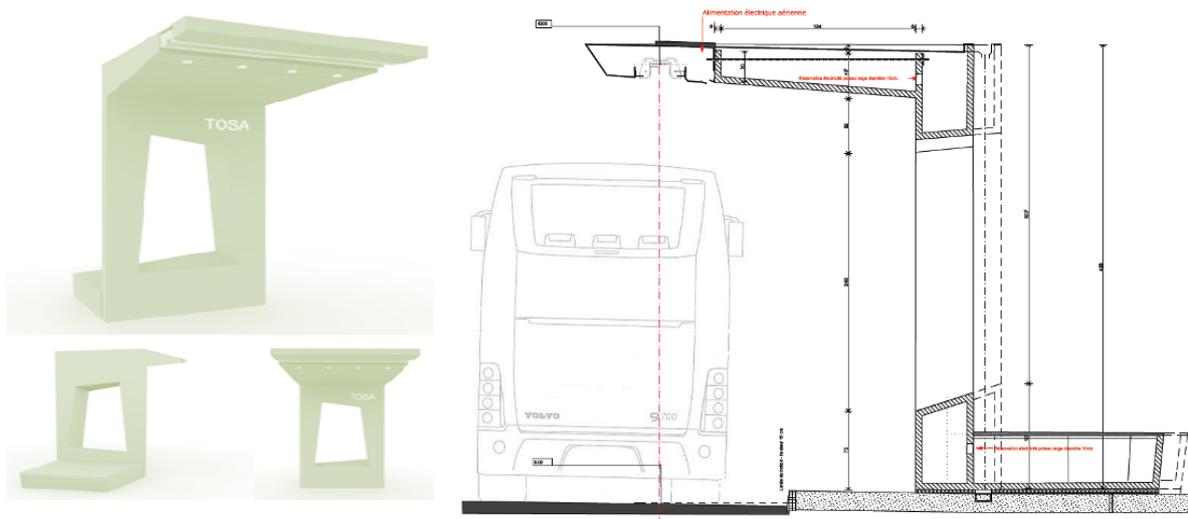


Figure 1 : Unit 1 with counterweight

Although the element has a very massive appearance, the concrete shell has a thickness of only 6 cm; the interior of the element is completely hollow.

Unit 2 to be placed close to Palexpo is exactly designed as Unit 1, with exception of the counterweight. This model has been placed above starter bars coming out of a foundation previously casted and linked with a concrete pour. Although weight was not an issue for Unit 2, it made sense to cast it in UHPFRC as well, since the formwork for Unit 1 could be reused with only minor modifications. With complex forms, the main cost driving factor is not material cost but formwork construction.

Since the architects modeled their design completely in 3D, geometrical data could be introduced directly into the finite element program (SCIA, Nemetschek). A linear-elastic calculation using material properties corresponding to a Holcim 707/710 concrete with a metallic fiber content of 3%, have been used (Fig. 2).

Design load cases according to SIA norms 260 and 261, as well as a stability load case and a lifting load case for transport and installation of the unit have been defined.

Analyzing the results, the main tensile stress does not exceed 3.7 N/mm^2 .

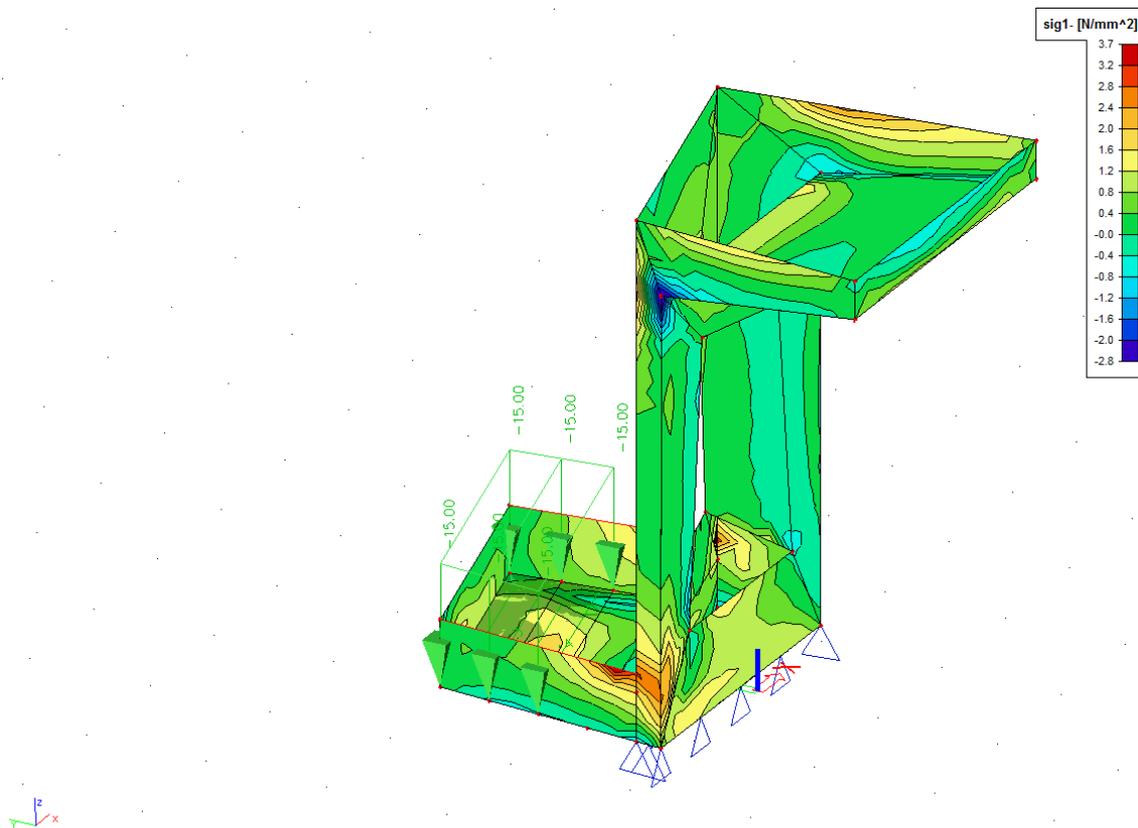


Figure 2 : main tensile stresses of Unit 1

Referring to the disadvantageous hypothesis material law for pure tension established for the concrete to be used (Figure 3), it confirms that for a tensile stress of 3.7 N/mm^2 linear elastic behavior can be assumed.

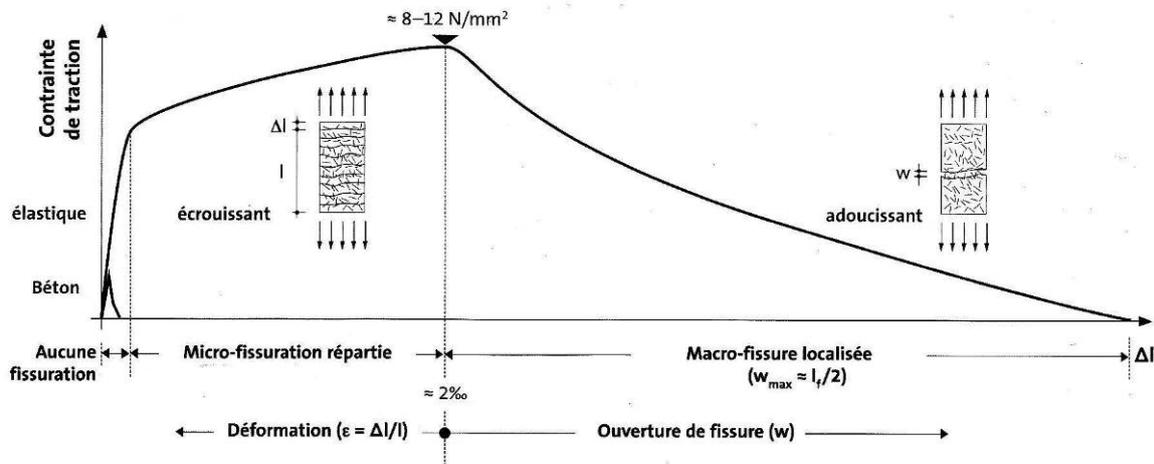


Figure 3 : Behavior of Holcim 707/710 under pure traction

2. PRACTICAL CONSIDERATIONS

Already before discussing the use of UHPFRC, it has been obvious for all participants, that power units should be produced as precast elements. Installation time of units should be kept as short as possible, in order not to block traffic.

Reasons for choosing UHPFRC as the material for the precast structure have been explained in the preceding chapter. Conferences [2], [3] showed significant progress in applying the material and reinforced the project team's decision.

Although precast plants exist in a sufficient number, those already experienced in using UHPFRC, or willing to accompany a prototype project, were limited. The project team was able to motivate Geneva-based Prelco. It has been decided to ask Holcim for technical support concerning the production of their UHPFRC.

Concrete used for precasting has been produced by Holcim in Morges and transported to Geneva to be poured. The formwork has been the biggest challenge for the precast plant. The plant would have preferred to cast Unit 1 in two pours: first the vertical charging unit and second the counterweight plate. Since the main tensile stress is located in the link between the counterweight plate and the vertical part (compare Figure 2), a secondary construction would have been necessary to link the two. This would have complicated the design and added weight. After discussion, it was decided to pour the power unit in one go.

Cut-outs have been foreseen for main electrical connections as well as for the LED-lighting installation at the top of the unit. All other holes were decided to be drilled afterwards.

The units have been precast and transported vertically.

3. MATERIAL TESTING

The project team at hepia evaluated the material provided by Holcim before pouring the two precast elements. Besides getting practical experience in the production and utilization of the material, the team wanted to answer the following questions:

- Is the material able to fill into the form correctly, without imperfections?
- Which is the right percentage of pigments to color the element?

3.1 Material production

Whereas a standard concrete can be mixed within approximately 2 minutes, the production of BFUP took around 25 minutes, whereas 20 minutes are needed for mixing. Pouring small quantities as it has been done for the tests is more complicated, since the material is a viscous paste (Fig. 4). Pouring bigger quantities is much easier; mixing time remains constant, however.



Figure 4 : Left – adding fibers to the premix, right - pouring

3.2 Compressive and tensile (flexural) strength testing

The material has been tested according the norm SN EN 12390-3 (compressive strength testing) and SN 12.390-5 (tensile (flexural) strength testing).

Different percentages of the pigment (5, 10 and 15 kg per m³ of finished concrete) have been added. We stayed deliberately under the recommendation of 3% pigment per cement volume unit. It was assumed, that with the high content of cement, a smaller percentage of pigment would be sufficient.

Compressive strength

Cubes tested had the dimensions of 10 x 10 x 10 cm and showed a compressive strength of 140 N/mm² after 7 days of hardening, a value which is on the lower bound of Holcim's specifications which varies between 140 – 170 N/mm².

Tensile (flexural testing) strength

Testing has been done using prisms of 4 x 4 x 16 cm (Fig. 5). After seven days, a tensile strength of 45 N/mm² has been obtained. This value is on the upper bound of Holcim specification which varies between 35-45 N/mm².

Pigmentation had no influence on the strength of the specimen. However, 15 kg pigment per m² were not sufficient to obtain the desired color (Fig. 6). For this reason, it was decided to produce the concrete for the qualification testing with 30 kg per m³ of finished material.

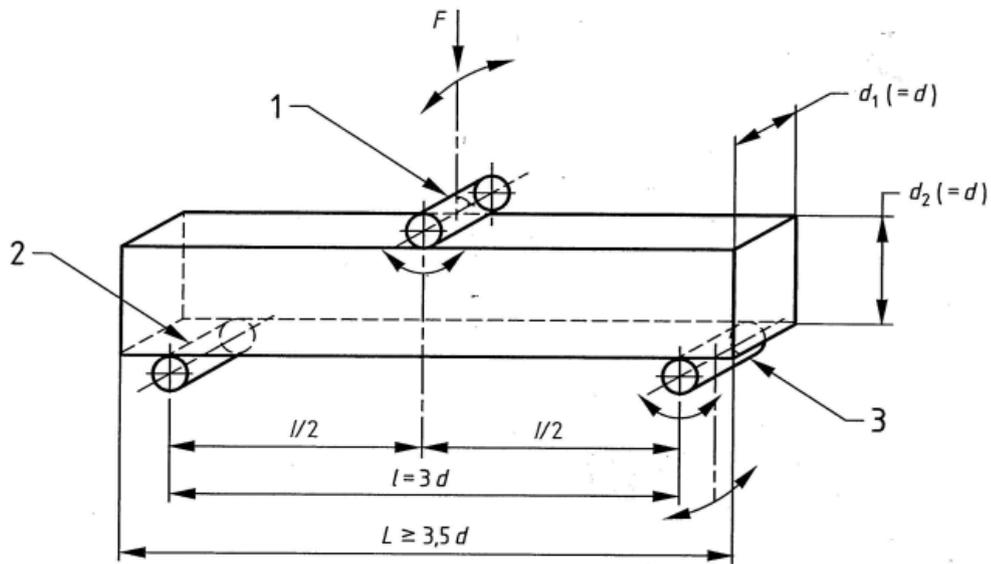


Figure 5 : Tensile (flexural) strength testing according to SN 12.390-5



Figure 6 : Tested prism with 15 kg pigment per m^3

3.3 Concrete flow – qualification testing

One part of the counterweight has been poured to challenge the following aspects:

- The influence of the formwork surface on the quality of the UHPFRC surface. Classical formwork panels as well as OSB boards have been used, one side with chamfer and another without.
- Concrete placement and auto compaction as well as fiber orientation. Visual aspect of the formwork and resulting surface is displayed in Figs 7 - 8.

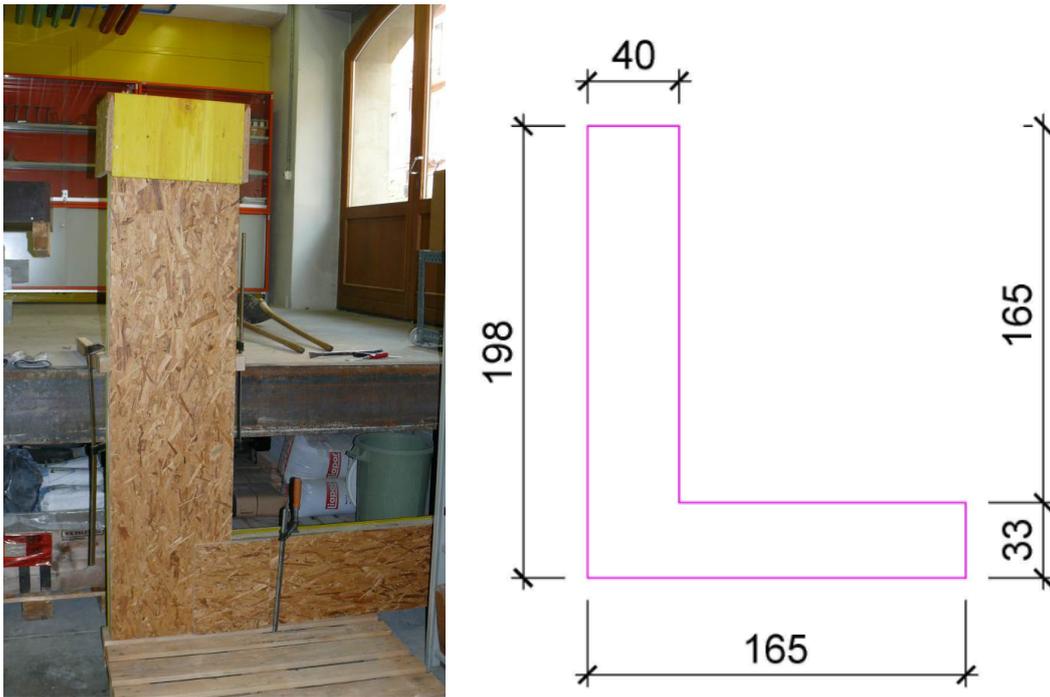


Figure 7 : Test formwork (height: 2 m, basis: 1.65 m), pigment: 30 kg per m³

No problem has been observed concerning the auto placement of the material. Although increasing the quantity of pigments to 30 kg per m³ gave a better result than other concentrations tested before, the color did not correspond perfectly to the team's expectation.



Figure 8 : Form removal of the element

Fibers do orient themselves very well under one condition: the formwork has to be perfectly tight and sharp edges have to be avoided. It should also be noted that concrete pressure on formwork is significantly higher than with conventional concrete.

4. PRODUCTION OF UNIT 1

It was planned to cast the element in one pour with UHPFRC delivered already pre-mixed. As preliminary testing showed, the concrete was able to place itself in every corner of the formwork. The fresh concrete is very fluid and the biggest grain has a diameter of only 0.5 mm. In consequence the formwork had to be designed to resist full hydrostatic pressure over a height of 4 m.

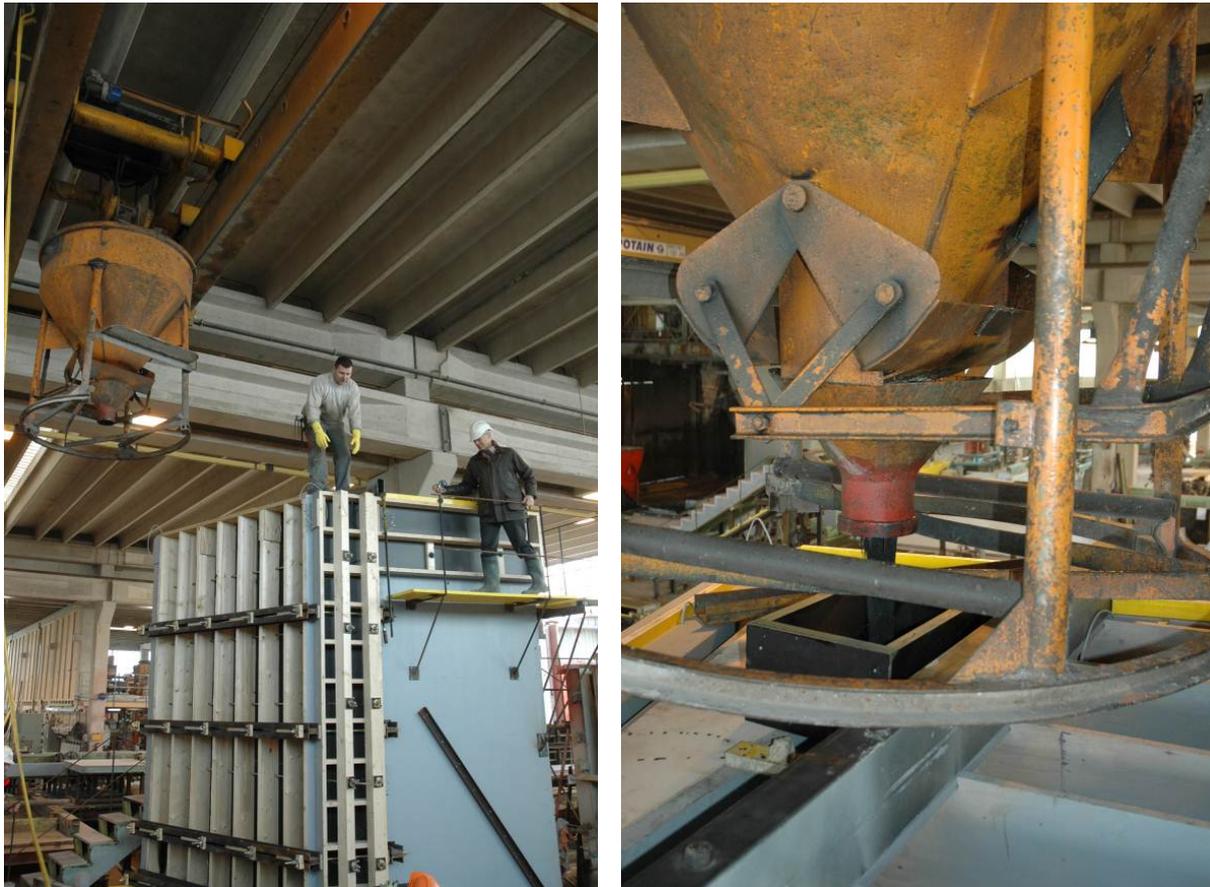


Figure 9: Pouring Unit 1 at Prelco, Geneva

The quantity of the material to be placed was much higher than in the laboratory testing, the flow out of the concrete bucket has not been a problem (Fig. 9).

To avoid cracks due to restrained concrete shrinkage, the pre-casting company retracted the inserts after a couple of hours.

5. UNITS INSTALLED

The two units have been transported to their installation ground and installed in april 2013. Installation time was very short, especially for Unit 1: it took less than one hour. The prototype line has been officially inaugurated the 26.05.2013 by the head of the Swiss Federal Department of Environment, Transport, Energy and Communication, Doris Leuthard.



Figure 10: Unit 2 installed at Palexpo exposition ground, Geneva (left) and unit 1 during inauguration (right).

6. CONCLUSIONS

The application of UHPFRC in the present case is a good example where a new material can serve architects as well as engineers to achieve their design objectives.

Despite the numerous publications concerning this material, it cannot be considered as an everyday product and used for mass production. It has shown its advantages when applied to existing structures for reinforcement as well as in special cases as demonstrated in the present paper.

Material production takes longer than for classical concrete. Adding small steel fibers, which we did by hand, is a harmful procedure. Automatic processes should be invented for this task.

Existing norms do not support the design of UHPFRC. Proposals are made by Brühwiler [3] and French or German associations [4] and [5]. Experience might show that stability issues should be considered to a much bigger extent than it is done for conventional concrete today.

Although it is often stated that material costs of UHPFRC are higher than for conventional concrete, the present project showed that the main cost driving factor is the complex formwork which has to resist to an important pressure. Since power units might be produced in a bigger series, this effect could be minimized.

ACKNOWLEDGEMENTS

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