Stress and Deformation Analysis of Batch Plates using Finite Element Method

P Lengvarský¹, J Bocko¹
Department of Applied Mechanics and Mechanical Engineering, Technical University of Košice, Letná 1/9, 042 00 Košice, Slovakia
pavel lengvarsky@tuke.sk

Abstract. The aim of the paper is to check the load-bearing capacity of batch plates. The batch plates are used for coating process of ball joints in a gas nitriding furnace. The plates have circular shape with two types of circular holes, the first type of holes are used for gas flow and the second type of holes are used for ball joints. The plates are laid on the supporting frame. The frame is supported in four suspension eyes, it is loaded by the actual weight of the plate and the plate is loaded by the weight of the stored ball joints. From the results is clear that adjustments need to be made on the supporting frame for the safe operation.

1. Introduction
The article deals with the analysis of plate structures used as transport devices during the gas nitriding of ball joints. Gas nitriding is a steel heat treatment process in which heat is used to diffuse nitrogen-rich gas onto the surface of the metal with the intention of hardening it. The process is carried out in a gas nitriding furnace where the ball joints are placed on batch plates [9]. The analysis described in the paper involves the analysis of these devices during the transport of the ball joints by the batch plates. The aim is to describe the complex static computation of batch plates and the design of their modifications with the specification of works defined by the customer. The specification includes the following activities:

Determine whether the individual batching plates (5 in total) are satisfactory in terms of load carrying capacity for the defined loads with a sufficient factor of safety.

a. Computation will be made for 4 types of slabs with a supporting frame (P01, P02, P03, and P05) and a supporting frame with a 5x5x3 steel grid.

b. The load on the plate with supporting frame is initiated by placing a ball joint with a nut in the hole in the batching plate.

c. The load of the supporting frame with the grid is initiated by placing the part itself, without the nut, directly on the grid.

d. All types of plates are Group B lifting devices.

The batching plates with supporting frame are in principle the same, differing only in the overall height, which is determined by the length of the pins and the center line, and at the same time the number of holes for the positioning of the coated parts with the nut. The diameter of the holes for the nut parts is identical, nominally 20.1 mm. The supporting frame is made up of a 10 mm thick laser-baked plate, reinforced in stressed areas by metal sheets welded to the structure. The batching plate is freely laid on the supporting frame, it is not firmly connected to the frame and therefore there is a possibility of its
interchangeability. The plate is a laser-baked plate with a thickness of 6 mm. The grid is freely laid on the supporting frame and consists of two parts. The size of the grid is 5 x 5 x 3 mm. For the production of the plates and the supporting frames and all components is used stainless steel 1.4301 [3].

The assembly of the supporting frame is shown in figure 1, in unfolded state in figure 2.

The plates are loaded through pins inserted in the holes, figure 3. The diameter of the nut neck in contact with the plate is 22 mm and the diameter of the hole on the plate is 20.1 mm. The contact with the plate is made in this location. The holes with a diameter of 12 mm are process holes, which do not serve for the positioning of parts. The diameter of the nut and holes is identical for all plates and projects; the plates differ only in the total number of holes.

For each plate with supporting frame, the originally required load capacities are defined. In the validation process, these plates will be loaded, relative to the standard, at twice the load capacity. For this reason, it is necessary to take into account twice the load capacity for computations, and in addition the dynamic coefficient must also be taken into account.

The supporting frame with the steel grid is shown in figure 4, in the partially unfolded state in figure 5. In this case, the parts laid on the grid are in contact with each other, figure 6. The simulated part has a contact area of 149.571 mm².
The fixing of the supporting frame is identical to that of the plate frame during handling. The attachment locations are shown in figure 7. A drawing of the anchoring device used to manipulate the plates is shown in figure 8.

**Figure 4.** Assembly of supporting frame with grid.

**Figure 5.** Supporting frame and grid in unfolded state.

**Figure 6.** Loading of supporting frame with grid.

**Figure 7.** Locations of supporting frame fixing.
2. Finite element analysis

Because the supporting frame and the plate have a complex shape with many stress concentrators, it is not possible to use classical analytical procedures to solve this problem [7, 10]. For this reason, the finite element method was used for the analysis [1, 2, 12]. The models representing supporting frame with the plates (P01, P02, P03 and P05) and supporting frame with 5x5x3 grid were supplied by the client. The required computations were carried out on these models according to the specification described in the introductory section. Following consultation with the contact person of the client organization, it was specified that the equipment is to be handled at a temperature slightly higher than the normal ambient temperature. The material properties used in the computations correspond to this. In all cases, the computations were carried out in the linear domain, i.e. in the domain of validity of Hooke's law, using a modulus of elasticity of $E = 200\,000\,\text{MPa}$ and Poisson's ratio of $\mu = 0.3$ [3]. Based on this, the stress and strain fields were then determined and design changes were proposed. The computations took into account the load coefficient defined for Group B lifting equipment [4-6, 8, 11].

2.1. Analysis of supporting frame with plates

This section describes the computations of the four plates with supporting frame (P01, P02, P03 and P05). Loads due to mass of the ball joints were applied at the edges of the holes for the respective studs. The computations were carried out on the basis of Table 1. With regard to the type of lifting device, a load factor from vertical inertia forces of 1.2 was used and the dead load of the device was also taken into account.

| Computation number | Plate type | Nominal load capacity (kg) | Testing load capacity (kg) |
|--------------------|------------|-----------------------------|-----------------------------|
| 1. P01             | 512        | 1024                         |
| 2. P02             | 628        | 1256                         |
| 3. P03             | 594        | 1188                         |
| 4. P05             | 595        | 1190                         |

As can be seen from Table 1, the largest load is applied to plate P02, which was the reason that in this paper we present the computation of this plate from a large number of computations. All plate types are similar. This model consists of about 430,000 volume finite elements with quadratic approximation and about 950,000 nodes. The boundary conditions applied to all models result from the way the batch plates are suspended. The batch plates are supported in four suspension lugs, are loaded by the plate's own

![Plate anchoring device](image_url)
weight and the load from the weight of the deposited ball joints, figure 9, with a corresponding coefficient of inertial forces of 1.2. The same boundary conditions were applied for all types of structures (including the model with grid). The plate P02 was loaded by testing load 1256 kg.

**Figure 9.** Boundary conditions and loads applied to the plate model.

In figure 10 we can see the field of resulting displacements of the model points. The largest value of 15.8 mm is in the central part of the plate. Figure 11 shows the field of equivalent stresses according to von Mises theory. The maximum stress of 351 MPa is in the area of the hole for the pin attachment, figure 12. Since the yield strength of the material used is 210 MPa, the plate is loaded in the plastic area. A detailed view of the location of maximum stress is shown in figure 12.

**Figure 10.** Field of resulting displacements of P02 plate (mm).

**Figure 11.** Field of equivalent stresses according to von Mises theory (MPa) in plate P02.
Due to the fact that in previous computations the maximum stress in the structure exceeded the yield strength of the material used, 210 MPa, the authors proceeded to increase the thickness of the frame to 14 mm, leaving the original thickness in the anchorage area so that the anchorage fixtures did not need to be changed. In this case, the largest displacement is 10.2 mm and the maximum equivalent stress is 187 MPa, i.e. under yield point of the material.

2.2. Analysis of supporting frame with grid
The loading acting on the supporting frame with the grid is initiated by placing the ball joints without nuts directly on the grid. The fixing of the supporting frame during handling is identical to that of the frame with plate. A quarter-scale model of the supporting frame with grid is shown in figure 13. The grid is modeled by beam elements.
The computation was accomplished with testing load 1400 kg. In figure 14 we can see the field of resulting displacements. The largest value of 18 mm is in the central part of the plate. Figure 15 shows the field of equivalent stresses according to von Mises theory in supporting frame. A detail of the area with a maximum stress of 391 MPa is shown in figure 16. Figure 17 shows the field of stresses in the grid. The extreme value of the stress is -188 MPa. Here again the supporting frame is loaded in the plastic area. As before the thickness of the frame was increased to 14 mm. In this case, the largest displacement is 12 mm and the maximum equivalent stress in frame is 210 MPa, i.e. at the yield point of material. The extreme value of stress in the grid is -174 MPa.

3. Conclusions
In accordance with the customer's requirement and on the basis of the documents supplied by the customer, a static computation of the batching plates for the gas nitriding process was carried out. The computation was carried out using the finite element method.

A summary of the computation results concerning the critical load on the batching plates is given in Table 2. For each computation, the load was multiplied by a dynamic coefficient of 1.2. From the analysis of the original structure with a 10 mm thick supporting frame, it is evident that the maximum stresses in the structure exceed the yield strength of 210 MPa. Since attempts to stiffen the supporting frame with reinforcing strips did not result in a sufficient reduction of the maximum stresses in the structure, the authors proposed to increase the thickness of the supporting frame to 14 mm, leaving the original thickness at the point of attachment to the anchorage device, figure 18.
### Table 2 Maximum stresses in batch plates.

| Plate type | Thickness of supporting frame (mm) | Mass of parts on the plate (kg) | Max. displacements of points (mm) | Max. von Mises stress (MPa) |
|------------|-----------------------------------|---------------------------------|-----------------------------------|---------------------------|
| P01        | 14                                | 1024 (testing)                  | 9                                 | 163                       |
|            | 10                                | 1256 (testing)                  | 15.8                              | 351                       |
| P02        | 10                                | 628 (nominal)                   | 9.9                               | 214                       |
|            | 14                                | 1256 (testing)                  | 10.2                              | 187                       |
| P03        | 14                                | 1188 (testing)                  | 9.8                               | 182                       |
| P05        | 14                                | 1190 (testing)                  | 9.8                               | 181                       |
| with grid  | 10                                | 1400 (testing)                  | 18                                | 391                       |
| with grid  | 14                                | 1400 (testing)                  | 12                                | 210                       |

**Figure 18.** Detail of the recess for fixing the supporting frame to the anchoring device.

The computation for fatigue resistance is carried out for load-bearing parts, fasteners and welds of cranes and lifting equipment components that are subjected to more than 20,000 load cycles during their technical life. The batching plates will, due to the technology in which they are used and its time-consuming nature, be subjected to a smaller number of cycles during their technical lifetime. The data (yield strength and ultimate strength) given in the material data sheet can therefore be used as a basis, i.e. the yield strength is 210 MPa and the ultimate strength is between 520 and 720 MPa [3].

Based on the results of the numerical modelling of the stresses in the batch plates, it was found that:

1. The maximum stresses in the originally designed structure at the largest test load exceed the yield strength.
2. The maximum test load that can be applied to the structure is 600 kg.
3. The maximum stresses in the structure at the largest test load could not be reduced below the yield strength of the material used by welding various reinforcing elements to the supporting frame.
4. The maximum stresses in the structure at the highest test load were reduced below the yield strength by increasing the thickness of the supporting frame to 14 mm for models P01, P02, P03, P05.

5. The maximum stress in the supporting frame structure with the mesh reaches 210 MPa, thus reaching the yield strength of the material used.

The computations were carried out for the supplied models. It is questionable to what extent there is a correspondence between the model and the real used plate, in terms of observing the distances between the holes for the positioning of the ball joints, on the real manufactured batch plates.

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