Anchor rods position assessment for connection of manipulating equipment to the transported structure

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Abstract. The manipulation and transport of baskets in which goods or components of various shapes are inserted is very often complicated due to manufacturing tolerances and deformations of the basket. Prediction of the connectivity of the basket and the transport device in the gripping points is very important from the point of view of safe transport of the basket. The methodology and procedure for determining the connectivity of the gripping elements of the transported device with the anchor holes of the basket columns is presented. In the analysis and evaluation of the connectivity of the basket with the transport device, the production tolerances of the basket and the transport device are taken into account and as well as the changes of important dimensions of the basket caused by different loading conditions.

1. Introduction
Manipulation and transport of goods or components with different shapes are very often performed by placing them in transport baskets. These baskets are usually connected to the manipulation device by various anchoring or gripping elements. It is evident that the manufacturing tolerances of the welded basket, as well as the deformation of the basket caused by the contents that are inserted into the basket, can significantly change the geometry of the basket. In addition, due to unexpected movement and the resulting change in the position of the basket contents, undesired deformation of the basket may occur. These geometrical changes in the basket shape, which would occur especially in places where the mutual anchoring of the basket to the manipulation device is expected, cause complications in their connection. As a result, it will not be possible to insert the gripping rods of the manipulation device into the anchor holes of the basket and the transport of the filled basket to the desired location will be impossible. This situation will caused absolutely unacceptable conditions in the case of transport of hazardous materials (for example, transport of radioactive waste - RAW), because the physical presence and activity leading to the correction of the condition that has occurred is absolutely excluded. In order to avoid these undesirable situations, detailed information on the manufacturing tolerances of the important basket dimensions and the gripping part of manipulation device have to be known. In addition, the some basket deformations are caused by predicted load cases, which are determined using stress-strain analyzes. These analyzes are performed on virtual computational models and resulting deformations have to be considered when the connectivity of the manipulation device to the basket is analyzed and evaluated. The procedure for analyzing and assessing the connectivity of the gripping parts of manipulation equipment to the transport basket for RAW materials is presented in this article.
2. Description of transport process

The manipulation device has four gripping rods (Figure 1) which are inserted into holes which have the shape of a "keyhole" and are located on the upper surface of the basket columns. After inserting the gripping rods into the holes of the "keyhole", these rods are rotated by 90 ° and a fixed connection of the basket with the manipulation device is achieved by means of transverse beams on the gripping rods [1].

![Figure 1. Configuration of basket and manipulation device [1].](image1)

Based on the manufacturing tolerances of the basket and the gripping rods of the manipulation device and the deformations of the basket, a specific state can occur under certain conditions, which causes a mutual collision between the gripping rods and the "keyholes" on the basket columns. In this situation, it is not possible to insert and rotate the gripping rods and connect the basket to the manipulation device.

An important effect on the connectivity of the basket and the manipulation device is caused mainly by the deformation of the basket due to the action of loading conditions, which may occur due to improper or unstable arrangement of the contents inserted in the basket. The problem that can occur is caused, for example, by the so-called "domino effect" (Figure 2) and subsequent support of the fragments inserted in the basket on one of the columns of the basket. This causes a significant deformation of the basket and a change in the position of the "keyholes" and then the insertion of the bars of the manipulation device into these holes is not possible.

![Figure 2. Basket model for a collision situation - "domino effect".](image2)
3. Analysis and assessment of connectivity of manipulation device and basket

The first fact that must be taken into account is the manufacturing tolerances of the basket, but also the manufacturing tolerances of the gripping rods of the handling equipment. From the actually made basket of the handling device, it is possible to determine by measurement the actual geometric configurations of the "keyholes" in the columns of the basket and the gripping rods. The coordinates of basket points $A_b, B_b, C_b, D_b$ (Table 1) and coordinates of gripping rod points $A_g, B_g, C_g, D_g$ (Table 2) are determined by measuring and they define the actual positions of the points.

The basket deformations (Figure 4a), which are determined by calculation using numerical simulations on a virtual basket model for the assumed load cases, change the positions of "keyholes" centers. The positions of the points $A_{b, d}, B_{b, d}, C_{b, d}, D_{b, d}$ (Table 3) are changed to the position $A_{b, d}, B_{b, d}, C_{b, d}, D_{b, d}$ (Table 4) in the coordinate system $x_b$ and $y_b$ (Figure 4b).

![Figure 3. Model of “keyholes” of basket (a) and gripping rods (b) for determination of actual dimensions.](image)

| $r_{b, A}$          | $x_{b, A} = 0$             | $y_{b, A} = 0$             |
|---------------------|--------------------------|--------------------------|
| $r_{b, B} = r_{b, BA}$ | $x_{b, B} = L_{b, BA} - d_b$ | $y_{b, B} = 0$             |
| $r_{b, C} = r_{b, CA}$ | $x_{b, C} = (L_{b, CA} - d_b) \cos \alpha_{b, A}$ | $y_{b, C} = (L_{b, CA} - d_b) \sin \alpha_{b, A}$ |
| $r_{b, D} = r_{b, DA}$ | $x_{b, D} = L_{b, BA} - d_b - (L_{b, DB} - d_b) \cos \alpha_{b, B}$ | $y_{b, D} = (L_{b, DB} - d_b) \sin \alpha_{b, B}$ |

$$\alpha_{b, A} = \arccos \left( \frac{(L_{b, CA} - d_b)^2 + (L_{b, BA} - d_b)^2 - (L_{b, CB} - d_b)^2}{2(L_{b, CA} - d_b)(L_{b, BA} - d_b)} \right)$$

$$\alpha_{b, B} = \arccos \left( \frac{(L_{b, BA} - d_b)^2 + (L_{b, DB} - d_b)^2 - (L_{b, DA} - d_{b, k})^2}{2(L_{b, BA} - d_b)(L_{b, DB} - d_b)} \right)$$
Table 2. Vector coordinates of gripping rods (center points of cross sections - A, B, C, D).

| r_{g,A} | x_{g,A} = 0 | y_{g,A} = 0 |
|---------|--------------|--------------|
| r_{g,B} = r_{g,BA} | x_{g,B} = L_{g,BA} - d_g | y_{g,B} = 0 |
| r_{g,C} = r_{g,CA} | x_{g,C} = (L_{g,CA} - d_g) \cos \alpha_{g,A} | y_{g,C} = (L_{g,CA} - d_g) \sin \alpha_{g,A} |
| r_{g,D} = r_{g,DA} | x_{g,D} = L_{g,BA} - d_g - (L_{g,DB} - d_g) \cos \alpha_{g,B} | y_{g,D} = (L_{g,DB} - d_g) \sin \alpha_{g,B} |

\[
\alpha_{g,A} = \arccos \left[ \frac{(L_{g,CA} - d_g)^2 + (L_{g,BA} - d_g)^2 - (L_{g,CB} - d_g)^2}{2(L_{g,CA} - d_g)(L_{g,BA} - d_g)} \right] \\
\alpha_{g,B} = \arccos \left[ \frac{(L_{g,BA} - d_g)^2 + (L_{g,DB} - d_g)^2 - (L_{g,DA} - d_g)^2}{2(L_{g,BA} - d_g)(L_{g,DB} - d_g)} \right] 
\]

Figure 4. Change in the position of the basket points due to deformation.

Table 3. Position changes of points (A, B, C, D) caused by basket deformation (Figure 4a).

| Displacement vectors | Point displacements (A', B', C', D') |
|----------------------|-----------------------------------|
| \Delta r_{hd,A} = \Delta x_{hd,A} \hat{i} + \Delta y_{hd,A} \hat{j} | \Delta x_{d,A} = \cdot \cdot \cdot | \Delta y_{d,A} = \cdot \cdot \cdot |
| \Delta r_{hd,B} = \Delta x_{hd,B} \hat{i} + \Delta y_{hd,B} \hat{j} | \Delta x_{d,B} = \cdot \cdot \cdot | \Delta y_{d,B} = \cdot \cdot \cdot |
| \Delta r_{hd,C} = \Delta x_{hd,C} \hat{i} + \Delta y_{hd,C} \hat{j} | \Delta x_{d,C} = \cdot \cdot \cdot | \Delta y_{d,C} = \cdot \cdot \cdot |
| \Delta r_{hd,D} = \Delta x_{hd,D} \hat{i} + \Delta y_{hd,D} \hat{j} | \Delta x_{d,D} = \cdot \cdot \cdot | \Delta y_{d,D} = \cdot \cdot \cdot |

Table 4. Position vectors of points (A, B, C, D) after basket deformation.

| Position vectors of points (A', B', C', D') to the coordinate system x, y (Figure 4b) |
|-----------------------------------------------|-----------------------------------------------|
| r_{hd,A} = x_{hd,A} \hat{i} + y_{hd,A} \hat{j} | x_{hd,A} = \Delta x_{hd,A} | y_{hd,A} = \Delta y_{hd,A} |
| r_{hd,B} = x_{hd,B} \hat{i} + y_{hd,B} \hat{j} | x_{hd,B} = x_{b} + \Delta x_{hd,B} | y_{hd,B} = y_{b} + \Delta y_{hd,B} |
| r_{hd,C} = x_{hd,C} \hat{i} + y_{hd,C} \hat{j} | x_{hd,C} = x_{c} + \Delta x_{hd,C} | y_{hd,C} = y_{c} + \Delta y_{hd,C} |
| r_{hd,D} = x_{hd,D} \hat{i} + y_{hd,D} \hat{j} | x_{hd,D} = x_{d} + \Delta x_{hd,D} | y_{hd,D} = y_{d} + \Delta y_{hd,D} |
To evaluate the mutual position of the corresponding points (A, B, C, D) of the basket and gripping rods (Table 5 and Table 6), it is necessary to express the position vectors for these points in the same coordinate system, i.e. to harmonize the coordinate system \((x_{bd}, y_{bd})\) (Figure 5a) with the coordinate system \((x_g, y_g)\) (Figure 5b).

![Figure 5. Models of coordinate systems \((x_{bd}, y_{bd})\) and \((x_g, y_g)\) for their harmonization.](image)

After harmonization of coordinate systems, it is possible to analyze the mutual position of gripping rods and "keyholes" in the basket columns (Figure 6). The mutual point positions of the gripping rods and the "keyholes" in the basket columns are defined by the coordinates \((x_{gb}, y_{gb})\) and by angles \(\varphi_{gb}\) (Table 7).

**Table 5.** Position of basket points \((A_{bd}, B_{bd}, C_{bd}, D_{bd})\) and angles to axis \(x_{bd}\) (Figure 5a).

| Vectors defining the position of the basket points \((x_{bd}, y_{bd})\) | \(x_{bd,BA} = x_{bd,B} - x_{bd,A}\) | \(y_{bd,BA} = y_{bd,B} - y_{bd,A}\) |
|---|---|---|
| \(r_{bd,BA} = x_{bd,BA} \mathbf{i} + y_{bd,BA} \mathbf{j}\) | \(x_{bd,CA} = x_{bd,C} - x_{bd,A}\) | \(y_{bd,CA} = y_{bd,C} - y_{bd,A}\) |
| \(r_{bd,CA} = x_{bd,CA} \mathbf{i} + y_{bd,CA} \mathbf{j}\) | \(x_{bd,DA} = x_{bd,D} - x_{bd,A}\) | \(y_{bd,DA} = y_{bd,D} - y_{bd,A}\) |
| \(r_{bd,DA} = x_{bd,DA} \mathbf{i} + y_{bd,DA} \mathbf{j}\) |

Angles of vectors \(r_{bd,BA}, r_{bd,CA}, r_{bd,DA}\) to axis \(x_{bd}\)

| \(\varphi_{bd,BA}\) | 0 |
|---|---|
| \(\varphi_{bd,CA}\) | \(\varphi_{bd,CA} = \arccos\left(\frac{r_{bd,BA} \cdot r_{bd,CA}}{|r_{bd,BA}| \cdot |r_{bd,CA}|}\right)\) |
| \(\varphi_{bd,DA}\) | \(\varphi_{bd,DA} = \arccos\left(\frac{r_{bd,BA} \cdot r_{bd,DA}}{|r_{bd,BA}| \cdot |r_{bd,DA}|}\right)\) |
Table 6. Position of gripping rods points (A_g, B_g, C_g, D_g) and angles to axis \( x_{bd} \) (Figure 5b).

| Vectors defining the position of the gripping rods \( (x_{g}, y_{g}) \) | \( x_{g,BA} = x_{g,B} - x_{g,A} \) | \( y_{g,BA} = y_{g,B} - y_{g,A} \) |
| --- | --- | --- |
| \( r_{g,BA} = x_{g,BA} \hat{i} + y_{g,BA} \hat{j} \) | \( x_{g,CA} = x_{g,C} - x_{g,A} \) | \( y_{g,CA} = y_{g,C} - y_{g,A} \) |
| \( r_{g,CA} = x_{g,CA} \hat{i} + y_{g,CA} \hat{j} \) | \( x_{g,DA} = x_{g,D} - x_{g,A} \) | \( y_{g,DA} = y_{g,D} - y_{g,A} \) |
| \( r_{g,DA} = x_{g,DA} \hat{i} + y_{g,DA} \hat{j} \) |

Angles of vectors \( r_{g,BA}, r_{g,CA}, r_{g,DA} \) to axis \( x_{g} \)

| \( \varphi_{g,BA} \) | 0 |
| --- | --- |
| \( \varphi_{g,CA} \) | \( \varphi_{g,CA} = \arccos \left( \frac{r_{g,BA} \cdot r_{g,CA}}{|r_{g,BA}| \cdot |r_{g,CA}|} \right) \) |
| \( \varphi_{g,DA} \) | \( \varphi_{g,DA} = \arccos \left( \frac{r_{g,BA} \cdot r_{g,DA}}{|r_{g,BA}| \cdot |r_{g,DA}|} \right) \) |

Figure 6. Harmonized coordinate systems \( (x_{bd}, y_{bd}) \) and \( (x_{g}, y_{g}) \).
Table 7. Position of gripping rods points A_g, B_g, C_g, D_g to basket points A_bd, B_bd, C_bd, D_bd.

| Angles of vectors r_{g,BA}, r_{g,CA}, r_{g,DA} after displacements (x_{gb,A}, y_{gb,A}) of point A_g to point A_{bd} and after rotation of gripping rods against the basket by angle \( \varphi_{gb,BA} \) to axis \( x_{gb,A} \) |
|---|
| \( \varphi_{gb,BA} = "set up" \) |
| \( \varphi_{gb,CA} = \varphi_{gb,CA} + \varphi_{gb,BA} \) |
| \( \varphi_{gb,DA} = \varphi_{gb,DA} + \varphi_{gb,BA} \) |

Position of gripping rods points A_g, B_g, C_g, D_g to basket points A_{bd}, B_{bd}, C_{bd}, D_{bd}

| \( x_{gb,A} = "set up" \) | \( y_{gb,A} = "set up" \) |
|---|---|
| \( x_{gb,B} = x_{gb,A} + |r_{g,BA}| \cos(\varphi_{gb,BA}) - x_{bd,BA} \) | \( y_{gb,B} = y_{gb,A} + |r_{g,BA}| \sin(\varphi_{gb,BA}) - y_{bd,BA} \) |
| \( x_{gb,C} = x_{gb,A} + |r_{g,CA}| \cos(\varphi_{gb,CA}) - x_{bd,CA} \) | \( y_{gb,C} = y_{gb,A} + |r_{g,CA}| \sin(\varphi_{gb,CA}) - y_{bd,CA} \) |
| \( x_{gb,D} = x_{gb,A} + |r_{g,DA}| \cos(\varphi_{gb,DA}) - x_{bd,DA} \) | \( y_{gb,D} = y_{gb,A} + |r_{g,DA}| \sin(\varphi_{gb,DA}) - y_{bd,DA} \) |

The collisions of the gripping rods and the "keyholes" of the basket columns (Figure 7) for the corresponding points (A, B, C, D) are determined and evaluated from the mutual relationship of the circles with the radii \( r_g \) and \( r_b \).

The equations of the circles each point (A, B, C, D) with radii \( r_g \) and \( r_b \) to the local coordinate systems \( (x_{gb}, y_{gb}) \) are expressed by the following equations

\[
x^2 + y^2 = r_b^2 \tag{1}
\]

\[
(x - x_{gb})^2 + (y - y_{gb})^2 = r_g^2 . \tag{2}
\]

These circles can have three mutual positions:

1. circle with radius \( r_g \) is inside a circle with radius \( r_b \) - the circles have no common point,
2. circle with radius \( r_g \) is inside a circle with radius \( r_b \) and the circles touch at one point - the circles have one common point,
3. circle with radius \( r_g \) intersects a circle with radius \( r_b \) - the circles have two common points.

It is obvious that a collision state when gripping rods are inserted into the "keyholes" of column baskets does not occur if the positions of the circles at all points satisfy the first condition.
4. Conclusions
The methodology and procedure for the analysis and assessment of the connectivity of the manipulation device and the transport basket are presented. In assessing connectivity, the manufacturing tolerances of the gripping rods and the basket are taken into account, as well as the deformations of the basket caused by the predicted loading conditions. This procedure provides a suitable method for avoiding possible complications during the transport of hazardous materials such as RAW materials.

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