ENERCON Excellence—Every project. Every day.	CALCULATION COVER SHEET	**CALC. NO.** RTL-001-CALC-ST-0201 **REV.** 1 **PAGE NO.** 1 of 22

Title:	RT-100 Lifting Structural Evaluation	**Client:**	Robatel Technologies, LLC
		Project:	RTL-001

Item	Cover Sheet Items	Yes	No
1	Does this calculation contain any open assumptions that require confirmation? (If **YES**, Identify the assumptions) ______	☐	☒
2	Does this calculation serve as an "Alternate Calculation"? (If **YES**, Identify the design verified calculation.) **Design Verified Calculation No.** ______	☐	☒
3	Does this calculation Supersede an existing Calculation? (If **YES**, identify the superseded calculation.) **Superseded Calculation No.** ______	☐	☒

Scope of Revision:

Updating vendor drawings, updating associated calculations to reflect these changes.

Revision Impact on Results:

N/A

Study Calculation ☐ **Final Calculation** ☒

Safety-Related ☒ **Non-Safety Related** ☐

(Print Name and Sign)

Originator: John Staples John Staples	**Date:** 8 oct 2012
Design Verifier: Amy Varallo	**Date:** 10/08/12
Approver: Curt Lindner	**Date:** 10/8/12

CALCULATION REVISION STATUS

REVISION	DATE	DESCRIPTION
0	9-12-2012	Initial Issue
1		Update vendor drawings, update associated calculations

PAGE REVISION STATUS

PAGE NO.	REVISION	PAGE NO.	REVISION
1-4	1		
5-6	0		
7, 11-22	1		

APPENDIX REVISION STATUS

APPENDIX NO.	PAGE NO.	REVISION NO.	APPENDIX NO.	PAGE NO.	REVISION NO.
1	1-2	0			
2	1-2	0			

Calculation Design Verification Plan:

Calculation to be reviewed for correctness of inputs, design criteria, analytical methods, acceptance criteria and numerical accuracy.

Stated objectives and conclusions shall be confirmed to be reasonable and valid.

Any assumptions shall be clearly documented and confirmed to be appropriate and verified based on sound engineering principles and practices.

(Print Name and Sign for Approval – mark "N/A" if not required)

Approver: **Curt Lindner**	**Date:** 10/8/12

Calculation Design Verification Summary:

Calculation has been designated as **Safety Related** as noted on the cover sheet.

Calculation has been verified to be mathematically correct and performed in accordance with appropriate design inputs, assumptions, analytical methods, design criteria and acceptance criteria.

The conclusions developed in the calculation are reasonable, valid and consistent with the purpose and scope.

Assumptions are appropriate and correct.

Based On The Above Summary, The Calculation Is Determined To Be Acceptable.

(Print Name and Sign)

Design Verifier: **Amy Varallo** Amy E. Varallo	**Date:** 10/8/12
Others:	**Date:**

ENERCON Excellence—Every project. Every day.	CALCULATION DESIGN VERIFICATION CHECKLIST	CALC. NO.	RTL-001-CALC-ST-0201
		REV.	1
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Item	CHECKLIST ITEMS	Yes	No	N/A
1	**Design Inputs -** Were the design inputs correctly selected, referenced (latest revision), consistent with the design basis, and incorporated in the calculation?	X		
2	**Assumptions** - Were the assumptions reasonable and adequately described, justified and/or verified, and documented?	X		
3	**Quality Assurance** - Were the appropriate QA classification and requirements assigned to the calculation?	X		
4	**Codes, Standards, and Regulatory Requirements** - Were the applicable codes, standards, and regulatory requirements, including issue and addenda, properly identified and their requirements satisfied?	X		
5	**Construction and Operating Experience** - Have applicable construction and operating experience been considered?	X		
6	**Interfaces** - Have the design-interface requirements been satisfied, including interactions with other calculations?	X		
7	**Methods** - Was the calculation methodology appropriate and properly applied to satisfy the calculation objective?	X		
8	**Design Outputs** - Was the conclusion of the calculation clearly stated, did it correspond directly with the objectives, and are the results reasonable compared to the inputs?	X		
9	**Radiation Exposure** - Has the calculation properly considered radiation exposure to the public and plant personnel?			X
10	**Acceptance Criteria** - Are the acceptance criteria incorporated in the calculation sufficient to allow verification that the design requirements have been satisfactorily accomplished?	X		
11	**Computer Software**- Is a computer program or software used, and if so, are the requirements of CSP 3.02 met?			X

COMMENTS

(Print Name and Sign)		
Design Verifier: Amy Varallo	Amy M. Varallo	**Date:** 10/8/12
Others:		**Date:**

Table of Contents

1.0 Purpose and Scope

Robatel Technologies is designing the RT-100 transport cask to transport radioactive waste in the form of dewatered resins and filters. The RT-100 transport cask is required to meet the requirements of 10CFR Part 71 (Ref. 3.1). This calculation demonstrates that this package satisfies the requirements of 10CFR71.45 (Ref. 3.1) under the normal lifting conditions. The NRC requirements in Reference 3.1 state that any lifting attachment that is a structural part of the package must be designed to withstand lifting stresses with appropriate safety factors. The RT-100 package is designed with two lifting pockets, attached to the cask sidewall, for lifting the assembled cask and with three removable lifting rings each on the upper impact limiter, lower impact limiter, primary lid and secondary lid. Failure of the lifting mechanism under excessive load must not impair the ability of the cask to meet the requirements of Subpart E of Reference 3.1. Any other structural part that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for lifting attachments. The purpose of this calculation is to structurally qualify the fully-loaded RT-100 transport cask for the loadings associated with lifting activities, including dead weight and payload weight, for the normal lifting conditions.

2.0 Summary of Results and Conclusions

All structural members have a factor of safety of greater than 1.0 under the most adverse effects from the lifting activities for the normal lifting conditions. The minimum factor of safety is 1.86 at the lifting pockets for the lifting of the assembled cask. All welds and connections are qualified for the design loads. The minimum weld factor of safety is 3.051 at the lifting pocket weld. The minimum bolt factor of safety is 1.75 at the lifting ring for the secondary lifting mechanisms (lids, impact limiters, etc.). The failure of the structural lifting attachments under excessive loads does not impair the ability of the cask to meet the other regulatory requirements of the cask. The results of the analysis show that the RT-100 cask can withstand the required lifting activities for the normal lifting conditions.

Therefore, the members and welds of the RT-100 transport cask are adequate for their design function under the normal lifting condition.

3.0 References

3.1 Nuclear Regulatory Commission, 10CFR Part 71, "Packaging and Transportation of Radioactive Material"

3.2 Drawings:

A. ROBATEL Industries Drawing RT100 PE 1001-1 Rev. E, "ROBATEL TRANSPORT PACKAGE RT100 GENERAL ASSY SHEET 1/2"
B. ROBATEL Industries Drawing RT100 PE 1001-2 Rev. E, "ROBATEL TRANSPORT PACKAGE RT100 GENERAL ASSY SHEET 2/2"
C. ROBATEL Industries Drawing 102885 PD 1012 Rev. B, "ROBATEL TRANSPORT PACKAGE RT100 S/E EMBALLAGE DETAILS COUVERCLE PRIMAIRE"
D. ROBATEL Industries Drawing 102885 PD 1013 Rev. B, "ROBATEL TRANSPORT PACKAGE RT100 S/E EMBALLAGE DETAILS COUVERCLE SECONDAIRE"
E. ROBATEL Industries Drawing 102885 PD 1031 Rev. B, "ROBATEL TRANSPORT PACKAGE RT100 S/E EMBALLAGE DETAILS CAPOT INFERIEUR"
F. ROBATEL Industries Drawing 102885 PD 1032 Rev. B, "ROBATEL TRANSPORT PACKAGE RT100 S/E EMBALLAGE DETAILS CAPOT SUPERIEUR"
G. ROBATEL Industries Drawing 102885 PD 3101 Rev. A, "WCS USA TRANSPORT PACKAGE RT100 S/E PALONNIER ENSEMBLE GENERAL"

3.3 Omer W. Blodgett, "Design of Welded Structures", 1966
3.4 ENERCON Calculation RTL-001-CALC-ST-0202 Rev. 0, "Tie-Down Structural Evaluation"
3.5 ENERCON Calculation RTL-001-CALC-ST-0203 Rev. 0, "Bolting Evaluation"
3.6 Erik Oberg, et. al., "Machinery's Handbook", 26th Edition
3.7 ASME B&PV Code, Section II, 2007
3.8 ASME B&PV Code, Section III, 2007
3.9 Joseph Edward Shigley & Larry D. Mitchell, "Mechanical Engineering Design", 4th Edition
3.10 ASME B1.13M-2005, "Metric Screw Threads: M Profile"
3.11 Warren C. Young and Richard G. Budynas, "Roark's Formulas for Stress and Strain", 7th Edition
3.12 ANSI N14.6-1978, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10000 pounds (4500 kg) or More for Nuclear Materials"
3.13 ENERCON Calculation RTL-001-CALC-ST-0101 Rev. 0, "RT-100 Weight and Center of Gravity Calculation"

4.0 Assumptions

4.1 The weight of the cask for the lifting evaluation is considered as the total weight of the cask and the maximum payload less the weight of the upper impact limiter. The cask lifting pockets can only be used with the upper impact limiter removed due to the configuration of the cask components (Ref. 3.2). This assumption is acceptable without further evaluation.

4.2 The cask lifting yoke (Ref. 3.2) will be used to lift the cask. The lifting yoke is designed to ensure that the lifting loads remain parallel to the sidewalls of the cask. The design of the lifting yoke is beyond the scope of this calculation and will not be considered further.

4.3 It is possible for the center of gravity of the payload to shift ±10% of the interior dimensions of the cask containment (Ref. 3.13). The payload is significantly lighter than the fully loaded cask. Therefore, this shift has no significant effect on the lifting conditions since the change in payload location will have an inconsequential effect of the center of gravity of the fully-assembled, loaded cask, resulting in a maximum change of less than 4cm in the overall center of gravity, which is approximately a 2.5% change (Ref. 3.13). Only the overall center of gravity location is used for this calculation. This assumption is acceptable without further evaluation.

There are no unverified assumptions in this calculation. Other design assumptions used, if any, will be noted and referenced as needed in the body of the calculation.

5.0 Design Inputs

5.1 The total weight of the fully assembled, unloaded cask is 33,824kg (Ref. 3.2).
5.2 The maximum payload weight is 15,000 lbs, or 6,803.9 kg (see Appendix 1). Conservatively, a value of 7,060kg will be used for the evaluation.
5.3 The weight of the upper impact limiter is 2,541kg (Ref. 3.2).
5.4 The weight of the primary lid is 3,648kg (Ref. 3.2).
5.5 The weight of the secondary lid is 857kg (Ref. 3.2).
5.6 Per 10CFR71.45(a) (Ref. 3.1), any lifting attachment that is a structural part of a package must be designed with a minimum safety factor of three (3) against yielding when used to lift the package in the intended manner. Per ANSI N14.6, a factor of five (5) against ultimate stress shall also be used. A factor of three against yielding stress and a factor of five against ultimate stress will therefore be used in the calculation of the cask lifting load.
5.7 The material properties used for the cask shell, the lead shielding and the lid bolts shall be as given in Table 1, unless noted otherwise.
5.8 The weight of the lower impact limiter is 2,448kg (Ref. 3.2).
5.9 A value of 9.81 m/s^2 will be used for the gravitational acceleration.
5.10 A value of 0.3 will be used for the Poisson's Ratio of all stainless steel in accordance with Table NF-2 of Reference 3.7.

Table 1 - Material Properties

Material	Temp. (°C)	Strength (MPa)			Young's Modulus (MPa)	Coefficient of Thermal Expansion (10^{-6} m/m)
		Yield (S_y)	Ultimate (S_u)	Membrane Allowable (S_m)		
X2CRNI19.11 (ASTM A240 Type 304L)[1]	-29 20 50 100 150 200 250	172.4 172.4 166.9 145.7 132.1 121.6 114.4	482.6 482.6 476.7 451.7 421.6 406.1 397.9	115.1 115.1 115.1 115.1 115.0 109.4 102.7	198.6 195.2 192.9 189.2 186.1 182.3 179.2	- 8.5 8.7 8.9 9.2 9.5 9.7
Europe Grade 10.9 (ASTM A354 Gr. BD) (Lid Bolts)[1]	-29 20 50 100 150 200 250	896.3 896.3 879.8 817.8 792.4 767.5 736.5	1034.2 1034.2 1034.2 1034.2 1034.2 1034.2 1034.2	206.8 206.8 206.8 206.8 206.8 206.8 206.8	204.8 201.4 199.7 196.8 193.7 191.2 187.6	- 6.4 6.5 6.7 6.9 7.1 7.3

Notes:

1. Material properties are taken from ASME B&PV Code, Section II, Part D (Ref. 3.7) by interpolation.

6.0 Methodology

The RT-100 transport cask will be a safety-related structure in accordance with 10CFR Part 71 (Ref. 3.1). The cask consists of a stainless steel containment structure with a lead shielding panel between the inner and outer cask wall, ductile stainless steel and foam upper and lower impact limiters, a pair of concentric, removable stainless steel cask lids and a pair of stainless steel lifting pockets on opposite sides of the cask body (Ref. 3.2). Per Section 4.1, the upper impact limiter will be removed and lifted separately during lifting operations. Per Section 5.6, a safety factor of three against yielding will be used in determining the weight of the assembled cask for lifting, for each of the impact limiters and for each of the cask lids.

The evaluation of the RT-100 cask lifting pockets and outer shell is provided in this document to show that they meet all of the applicable requirements of 10CFR71.45 (Ref. 3.1) for the combined weight of the cask and the payload. The evaluation of the RT-100 upper impact limiter, lower impact limiter, primary lid and secondary lid lifting rings are provided in this document to show that they meet all of the applicable requirements of 10CFR71.45 (Ref. 3.1) for the dead weight of the component being lifted. The lifting rings and bolts utilized for lifting will be checked for lifting mechanism failure, cask tear out failure and weld failure, as applicable. An evaluation is provided to demonstrate that failure of the lifting pockets under excessive load will not impair the cask's ability to meet the other applicable requirements of Reference 3.1.

7.0 Calculations

<u>NOTE</u>: In many cases, calculations are made using exact values, not the rounded numbers shown. Therefore, in certain situations, the numbers displayed may not be capable of providing the final solution. Using exact numbers, however, provides the most accurate solution possible.

7.1 <u>Load Calculation</u>

See Section 0 (Design Inputs) of this calculation for a list of all applicable loads and Section 6.0 (Methodology) for the applicable methodology and lifting conditions. The detailed calculation of loads follows.

Cask Weight, W_C = 33824kg (see Section 5.1)

Payload Weight, W_P = 7060kg (see Section 5.2)

Upper Impact Limiter Weight, W_{UL} = 2541kg (see Section 5.3)

Total Lifting Weight, W = $W_C + W_P - W_{UL} = 33824 + 7060 - 2541 =$ 38343kg, use 38,500kg

7.2 <u>Tie-Down Arm Lifting Evaluation</u>

Per 10CFR71.45(a) (Ref. 3.1), any structural part of the package, other than those components designated and designed for lifting activities, that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for lifting attachments. The tie-down arms can be rendered inoperable through the use of padlocks on the tie-down eyes provided in each of the tie-down arms for securing the load (Refs. 3.2 and 3.4). The tie-down arms will not be used for lifting and therefore do not need to be designed for the lifting loads. The tie-down arms are acceptable without further evaluation.

7.3 Primary Lid Lifting Evaluation

The primary lid can be lifted separately from the rest of the cask by the three removable M20 lifting rings shown in Reference 3.2. The primary lid will be evaluated for the working load limit in the lifting rings and for the tear-out stresses in the lid from the lifting activities. The lifting rings for the primary lid can only be used when the cask lid is separated from the cask body. The secondary cask lid is also removable, so the primary lid may be lifted with the secondary lid attached or separated from the primary lid. Conservatively, the combined primary and secondary lid is used for the lifting evaluation.

Primary Lid Design Information

Primary Lid Weight, W_{PL} =	3648kg (see Section 5.4)	
Secondary Lid Weight, W_{SL} =	857kg (see Section 5.5)	
Total Lid Lifting Weight, W_L =	$W_{PL} + W_{SL} = 3648 + 857 =$	4505kg, use 4,600kg
Number of Lifting Rings, n_r =	3 (Ref. 3.2)	

Check Lifting Ring Working Loads

The lifting rings on the primary lid will only be used for lifting when the lid is detached from the cask body, and will be rendered inoperable by removing the rings from the lid when the cask is assembled. The rings are therefore not considered to be a structural part of the package and do not need to be designed for the factor of safety against yielding (see Section 5.6).

Lifting Ring Load, P_r =	$\frac{W_L}{n_r} = \frac{4600}{3} =$	1533kg
Ring Working Load Limit, $P_{r,max}$ =		3000kg (Ref. 3.2)
Factor of Safety, FS =	$\frac{P_{r,max}}{P_r} = \frac{3000}{1533} =$	1.96 > 1.0

Check Cask Metal Tear-out Stresses

Because the cask material is weaker than the lifting ring material, failure will occur at the root of the cask material threads. The minimum required thread engagement length to prevent cask material failure is determined in accordance with Reference 3.6. Since the constants in the equation assume customary units, the metric units used in this calculation will be converted for determination of the required engagement length.

Minimum Engagement Length, L_e =

$$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]}$$

where:

Sbt = Bolt External Thread Tensile Strength, psi

Ab = Stress Area of Bolt External Threads, in2

Sct = Cask Internal Thread Tensile Strength, psi

n = Number of Threads per Inch

Ds,min = Minimum Major Bolt Diameter, in

En,max = Maximum Pitch Diameter of Internal Thread, in

The engagement length equation incorporates the engagement length of Formula 1 (Ref. 3.6) and the internal thread stripping reduction, J, of Formula 3 and Formula 4 (Ref. 3.6), which applies when the internal thread material is weaker than the external thread material of the bolt.

Bolt Tensile Strength, S_{bt} = 1,034.21 MPa = 150,000 psi (see Table 1)

Bolt Stress Area, A_b = 245.0 mm² = 0.38 in² (Ref. 3.9)

Cask Tensile Strength, S_{ct} = 482.6 MPa = 70,000 psi (see Table 1)

Thread Pitch, p = 2.50 mm = 0.098 in (Ref. 3.9)

Thread Spacing, n = $\frac{1}{p} = \frac{1}{0.098} =$ 10.16 threads/in

Minimum Bolt Diameter, $D_{s,min}$ = 19.623 mm = 0.773 in (Table 14, Ref. 3.10)

Maximum Pitch Diameter, $E_{n,max}$ = 17.744 mm = 0.699 in (Table 15, Ref. 3.10)

Minimum Engagement Length, L_e =

$$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]} =$$

$$\frac{150000 \times 2 \times 0.38}{70000 \times \pi \times 10.16 \times 0.773 \times \left[\frac{1}{2 \times 10.16} + 0.57735 \times (0.773 - 0.699)\right]} =$$

0.72 in = 18.2 mm

Provided Engagement Length, L_{ep} = 32.0 mm (Part 07730-20, see Appendix 2)

Factor of Safety, FS = $\frac{L_{ep}}{L_e} = \frac{32.0}{18.2} =$ 1.75 > 1.0

Therefore, it is concluded that the RT-100 primary lid lifting rings are acceptable for the applied loads during the required lifting activities.

7.4 Secondary Lid Lifting Evaluation

The secondary lid can be lifted separately from the rest of the cask by the three removable lifting rings shown in Reference 3.2. The primary and secondary lids can be lifted together or independently, as needed. The combined primary and secondary lid are evaluated for lifting in Section 7.3, so this evaluation is only considering the lifting of the secondary lid. The secondary lid will be evaluated for the working load limit in the lifting rings and for the tear-out stresses in the lid from lifting activities. The lifting rings for the secondary lid can only be used when the cask lid is separated from the cask body.

Secondary Lid Design Information

Secondary Lid Weight, W_{SL} = 857kg (see Section 5.5)

Total Lid Lifting Weight, $W_L = W_{SL}$ = 857kg, use 900kg

Number of Lifting Rings, n_r = 3 (Ref. 3.2)

Check Lifting Ring Working Loads

The lifting rings on the secondary lid will only be used for lifting when the lid is detached from the cask and will rendered inoperable by removing the rings from the lid when the cask is assembled. The rings are therefore not considered to be a structural part of the package and do not need to be designed for the factor of safety against yielding (see Section 5.6).

Lifting Ring Load, P_r = $\frac{W_L}{n_r} = \frac{900}{3} =$ 300kg

Ring Working Load Limit, $P_{r,max}$ = 3000kg (Ref. 3.2)

Factor of Safety, FS = $\frac{P_{r,max}}{P_r} = \frac{3000}{300} =$ 10.00 > 1.0

Check Cask Metal Tear-out Stresses

Because the cask material is weaker than the lifting ring material, failure will occur at the root of the cask material threads. The minimum required thread engagement length to prevent cask material failure is determined in accordance with Reference 3.6. Since the constants in the equation assume customary units, the metric units used in this calculation will be converted for determination of the required engagement length.

Minimum Engagement Length, L_e = $$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]}$$

where:

S_{bt} = Bolt External Thread Tensile Strength, psi

A_b = Stress Area of Bolt External Threads, in^2

S_{ct} = Cask Internal Thread Tensile Strength, psi

n = Number of Threads per Inch

$D_{s,min}$ = Minimum Major Bolt Diameter, in

$E_{n,max}$ = Maximum Pitch Diameter of Internal Thread, in

The engagement length equation incorporates the engagement length of Formula 1 (Ref. 3.6) and the internal thread stripping reduction, J, of Formula 3 and Formula 4 (Ref. 3.6), which applies when the internal thread material is weaker than the external thread material of the bolt.

Bolt Tensile Strength, S_{bt} = 1,034.21 MPa = 150,000 psi (see Table 1)

Bolt Stress Area, A_b = 245.0 mm² = 0.38 in² (Ref. 3.9)

Cask Tensile Strength, S_{ct} = 482.6 MPa = 70,000 psi (see Table 1)

Thread Pitch, p = 2.50 mm = 0.098 in (Ref. 3.9)

Thread Spacing, n = $\frac{1}{p} = \frac{1}{0.098} =$ 10.16 threads/in

Minimum Bolt Diameter, $D_{s,min}$ = 19.623 mm = 0.773 in (Table 14, Ref. 3.10)

Maximum Pitch Diameter, $E_{n,max}$ = 17.744 mm = 0.699 in (Table 15, Ref. 3.10)

Minimum Engagement Length, L_e = $$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]} =$$

$$\frac{150000 \times 2 \times 0.38}{70000 \times \pi \times 10.16 \times 0.773 \times \left[\frac{1}{2 \times 10.16} + 0.57735 \times \left(0.773 - 0.699\right)\right]} =$$ 0.72 in = 18.2 mm

Provided Engagement Length, L_{ep} = 32.0 mm (Part 07730-20, see Appendix 2)

Factor of Safety, FS = $\frac{L_{ep}}{L_e} = \frac{32.0}{18.2} =$ 1.75 > 1.0

Therefore, it is concluded that the RT-100 secondary lid lifting rings are acceptable for the applied loads during the required lifting activities.

7.5 Upper Impact Limiter Lifting Evaluation

The upper impact limiter can be lifted separately from the rest of the cask by the three removable M20 lifting rings shown in Reference 3.2. The upper impact limiter will be evaluated for the working load limit in the lifting rings and for tear-out stresses in the impact limiter from the lifting activities. The lifting rings for the impact limiter can only be used when the impact limiter is separated from the cask body.

Upper Impact Limiter Design Information

Impact Limiter Weight, W_{UL} = 2541kg (see Section 5.3)

Total Lifting Weight, $W_L = W_{UL}$ = 2541kg, use 2,700kg

Number of Lifting Rings, n_r = 3 (Ref. 3.2)

Check Lifting Ring Working Loads

The lifting rings on the upper impact limiter will only be used for lifting when the impact limiter is detached from the cask body, and will be rendered inoperable by removing the rings from the impact limiter when the cask is assembled. The rings are therefore not considered to be a structural part of the package and do not need to be designed for the factor of safety against yielding (see Section 5.6).

Lifting Ring Load, P_r = $\frac{W_L}{n_r} = \frac{2700}{3} =$ 900kg

Ring Working Load Limit, $P_{r,max}$ = 3000kg (Ref. 3.2)

Factor of Safety, FS = $\frac{P_{r,max}}{P_r} = \frac{3000}{900} =$ 3.33 > 1.0

Check Cask Metal Tear-out Stresses

Because the cask material is weaker than the lifting ring material, failure will occur at the root of the cask material threads. The minimum required thread engagement length to prevent cask material failure is determined in accordance with Reference 3.6. Since the constants in the equation assume customary units, the metric units used in this calculation will be converted for determination of the required engagement length.

Minimum Engagement Length, L_e = $$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]}$$

where:

S_{bt} = Bolt External Thread Tensile Strength, psi

A_b = Stress Area of Bolt External Threads, in^2

S_{ct} = Cask Internal Thread Tensile Strength, psi

n = Number of Threads per Inch

$D_{s,min}$ = Minimum Major Bolt Diameter, in

$E_{n,max}$ = Maximum Pitch Diameter of Internal Thread, in

The engagement length equation incorporates the engagement length of Formula 1 (Ref. 3.6) and the internal thread stripping reduction, J, of Formula 3 and Formula 4 (Ref. 3.6), which applies when the internal thread material is weaker than the external thread material of the bolt.

Bolt Tensile Strength, S_{bt} = 1,034.21 MPa = 150,000 psi (see Table 1)

Bolt Stress Area, A_b = 245.0 mm² = 0.38 in² (Ref. 3.9)

Cask Tensile Strength, S_{ct} = 482.6 MPa = 70,000 psi (see Table 1)

Thread Pitch, p = 2.50 mm = 0.098 in (Ref. 3.9)

Thread Spacing, n = $\frac{1}{p} = \frac{1}{0.098} =$ 10.16 threads/in

Minimum Bolt Diameter, $D_{s,min}$ = 19.623 mm = 0.773 in (Table 14, Ref. 3.10)

Maximum Pitch Diameter, $E_{n,max}$ = 17.744 mm = 0.699 in (Table 15, Ref. 3.10)

Minimum Engagement Length, L_e = $$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]} =$$

$$\frac{150000 \times 2 \times 0.38}{70000 \times \pi \times 10.16 \times 0.773 \times \left[\frac{1}{2 \times 10.16} + 0.57735 \times \left(0.773 - 0.699\right)\right]} =$$ 0.72 in = 18.2 mm

Provided Engagement Length, L_{ep} = 32.0 mm (Part 07730-20, see Appendix 2)

Factor of Safety, FS = $\frac{L_{ep}}{L_e} = \frac{32.0}{18.2} =$ 1.75 > 1.0

Therefore, it is concluded that the RT-100 upper impact limiter lifting rings are acceptable for the applied loads during the required lifting activities.

7.6 Lower Impact Limiter Lifting Evaluation

The lower impact limiter can be lifted separately from the rest of the cask by the use of three of the twelve M36 bolts, evenly spaced around the perimeter of the impact limiter, shown in Reference 3.2. The lower impact limiter will be evaluated for the bolt stresses and for tear-out stresses in the impact limiter from the lifting activities. The bolts can only be used for lifting when the impact limiter is separated from the cask body.

Lower Impact Limiter Design Information

Impact Limiter Weight, W_{LL} = 2448kg (see Section 5.8)

Total Lifting Weight, $W_L = W_{LL}$ = 2448kg, use 2600kg

Number of Lifting Bolts, n_b = 3 (Ref. 3.2)

Gravitational Acceleration, g = 9.81 m/s² (see Section 5.9)

Check Bolt Stresses

The bolts on the lower impact limiter will only be used for lifting when the impact limiter is detached from the cask body, and will be rendered inoperable by securing them to the cask body as part of the assembled cask. The bolts are therefore not considered to be a structural part of the package with respect to lifting and do not need to be designed for the factor of safety against yielding (see Section 5.6). Since the arrangement of the cables or straps used to lift the lower impact limiter may vary, the total lifting load is conservatively considered simultaneously in the vertical and horizontal directions.

Bolt Tension, T = $\frac{W_L \times g}{n_b} = \frac{2600 \times 9.81}{3} =$ 8502.0 N

Bolt Shear, V = $\frac{W_L \times g}{n_b} = \frac{2600 \times 9.81}{3} =$ 8502.0 N

Bolt Stress Area, A_b = 817.0 mm² = 0.000817 m² (Ref. 3.9)

Bolt Tensile Stress, σ_1 = $\frac{T}{A_b} = \frac{8502.0}{0.000817 \times 1000} =$ 10406.4 kN/m² = 10.4 MPa

Bolt Shear Stress, τ = $\frac{V}{A_b} = \frac{8502.0}{0.000817 \times 1000} =$ 10406.4 kN/m² = 10.4 MPa

Maximum Principal Stress, σ_{p1} = $\frac{1}{2} \times \left[\sigma_1 + \sqrt{\sigma_1^2 + 4 \times \tau^2}\right] =$

$\frac{1}{2} \times \left[10.4 + \sqrt{10.4^2 + 4 \times 10.4^2}\right] =$ 16.8 MPa (Ref. 3.11)

Maximum Principal Stress, σ_{p2} = $\frac{1}{2} \times \left[\sigma_1 - \sqrt{\sigma_1^2 + 4 \times \tau^2}\right] =$

$\frac{1}{2} \times \left[10.4 - \sqrt{10.4^2 + 4 \times 10.4^2}\right] =$ -6.4 MPa (Ref. 3.11)

Maximum Shear Stress, τ_{max} = $\frac{\sigma_{p1} - \sigma_{p2}}{2} = \frac{16.8 - (-6.4)}{2} =$ 11.6 MPa (Ref. 3.11)

Bolt Yield Stress, S_y = 896.3 MPa (see Table 1, room temperature used)

Allowable Shear Stress, S_a = $0.6 \times S_y = 0.6 \times 896.3 =$ 537.8 MPa

Factor of Safety, FS = $\frac{S_a}{\tau_{max}} = \frac{537.8}{11.6} =$ 46.22 > 1.0

Check Cask Metal Tear-out Stresses

Because the cask material is weaker than the bolt material, failure will occur at the root of the cask material threads. The minimum required thread engagement length to prevent cask material failure is determined in accordance with Reference 3.6. Since the constants in the equation assume customary units, the metric units used in this calculation will be converted for determination of the required engagement length.

Minimum Engagement Length, L_e = $$\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]}$$

where:

S_{bt} = Bolt External Thread Tensile Strength, psi

A_b = Stress Area of Bolt External Threads, in^2

S_{ct} = Cask Internal Thread Tensile Strength, psi

n = Number of Threads per Inch

$D_{s,min}$ = Minimum Major Bolt Diameter, in

$E_{n,max}$ = Maximum Pitch Diameter of Internal Thread, in

The engagement length equation incorporates the engagement length of Formula 1 (Ref. 3.6) and the internal thread stripping reduction, J, of Formula 3 and Formula 4 (Ref. 3.6), which applies when the internal thread material is weaker than the external thread material of the bolt.

Bolt Tensile Strength, S_{bt} = 1,034.21 MPa = 150,000 psi (see Table 1)

Bolt Stress Area, A_b = 817.0 mm² = 1.27 in² (Ref. 3.9)

Cask Tensile Strength, S_{ct} = 482.63 MPa = 70,000 psi (see Table 1)

Thread Pitch, p = 4.00 mm = 0.157 in (Ref. 3.9)

Thread Spacing, n = $\frac{1}{p} = \frac{1}{0.157} =$ 6.35 threads/in

Minimum Bolt Diameter, $D_{s,min}$ = 35.465 mm = 1.396 in (Table 14, Ref. 3.10)

Maximum Pitch Diameter, $E_{n,max}$ = 33.342 mm = 1.313 in (Table 15, Ref. 3.10)

Minimum Engagement Length, L_e = $\frac{S_{bt} \times 2 \times A_b}{S_{ct} \times \pi \times n \times D_{s,min} \times \left[\frac{1}{2 \times n} + 0.57735 \times \left(D_{s,min} - E_{n,max}\right)\right]} =$

$$\frac{150000 \times 2 \times 1.27}{70000 \times \pi \times 6.35 \times 1.396 \times \left[\frac{1}{2 \times 6.35} + 0.57735 \times (1.396 - 1.313)\right]} = \quad 1.53 \text{ in} = 39.0 \text{ mm}$$

Provided Engagement Length, L_{ep} = 75.0 mm (Ref. 3.2)

Factor of Safety, FS = $\frac{L_{ep}}{L_e} = \frac{75.0}{39.0} =$ 1.92 > 1.0

Therefore, it is concluded that the RT-100 lower impact limiter bolts are acceptable for the applied loads during the required lifting activities.

7.7 Assembled Cask Lifting Evaluation

The cask will be lifted by the use of the two lifting pockets on the cask sidewalls, on opposite sides of the cask body. The assembled cask will be lifted with the upper impact limiter removed to accommodate the connection between the special hoisting device and the lifting pockets. The cask lifting load will therefore be considered as the total weight of the fully assembled cask, including the payload, but with the impact limiter load removed and considered to be lifted separately (see Section 7.5). The lifting pockets will be evaluated for the connection stresses, weld stresses and cask body stresses due to the required lifting activities.

Cask Design Information

Total Lifting Weight, W = 38500kg (see Section 7.1)

Number of Lifting Pockets, n_p = 2 (Ref. 3.2)

Gravitational Acceleration, g = 9.81 m/s² (see Section 5.9)

Check Lifting Pocket Eye Tear-out Stresses

The cask lifting pocket can only be used with the upper impact limiter removed. The lifting pockets will be used for lifting the assembled cask body, without the upper impact limiter, and will be rendered inoperable by removing the lifting attachment from the lifting pocket during transport. The lifting pockets are considered to be a structural part of the package with respect to lifting and therefore do need to be designed for the factor of safety against yielding and ultimate stresses (see Section 5.6). A special lifting yoke (Ref. 3.2) will be used to lift the assembled cask body and to ensure that the lifting straps or cables remain parallel to the body of the cask during lifting operations.

Yielding Factor of Safety, f_{sy} = 3 (see Section 5.6)

Ultimate Factor of Safety, f_{su} = 5 (see Section 5.6)

Vertical Shear Load, P_v = $\frac{W \times g}{n_p} = \frac{38500 \times 9.81}{2} \times \frac{1\,\text{kN}}{1000\,\text{N}} =$ 188.8 kN

The critical tear-out area for each cask lifting pocket is determined from Reference 3.2.

Lifting Eye Diameter, d_e = 67 mm = 0.067 m

Lifting Pocket Length, L_p = 201 mm = 0.201 m

Lifting Pocket Edge Distance, d_p = 55 mm = 0.055 m

Lifting Eye Tear-out Distance, d_{to} = $L_p - d_p - \frac{d_e}{2} = 0.201 - 0.055 - \frac{0.067}{2} =$ 0.1125 m

Lifting Pocket Thickness, t_p = 37 mm = 0.037 m

Tear-out Area, A_{to} = $d_{to} \times t_p = 0.1125 \times 0.037 =$ 0.00416 m²

Nominal Tear-out Stress, τ = $\frac{P_v}{A_{to}} = \frac{188.8}{0.00416} =$ 45367.6 kN/m² = 45.4 MPa

Cask Yield Strength, S_y = 172.4 MPa (see Table 1)

Cask Ultimate Tensile Strength, S_u = 482.6 MPa (see Table 1)

Allowable Shear Stress, τ_{Ay} = $\frac{S_y}{f_{sy}} = \frac{172.4}{3} =$ 57.5 MPa

Allowable Shear Stress, τ_{Au} = $\frac{S_u}{f_{su}} = \frac{482.6}{5} =$ 96.5 MPa

Factor of Safety, FS = $\frac{\tau_{Ay}}{\tau} = \frac{57.5}{45.4} =$ 1.27 > 1.0

Factor of Safety, FS = $\frac{\tau_{Au}}{\tau} = \frac{96.5}{45.4} =$ 2.13 > 1.0

Check Lifting Pocket Weld Stresses

The stresses in the welds attaching the lifting pocket to the cask outer shell are found by applying the shear load from the lifting pockets to the weld around the perimeter of the plate. Based on the safety factors for the lifting pocket, yielding will control the weld evaluation.

Weld Lifting Load, P_w = $f_{sy} \times P_v = 3 \times 188.8 =$ 566.5 kN, use 600 kN

Cask Tensile Stress, S_y = 172.4 MPa (see Table 1)

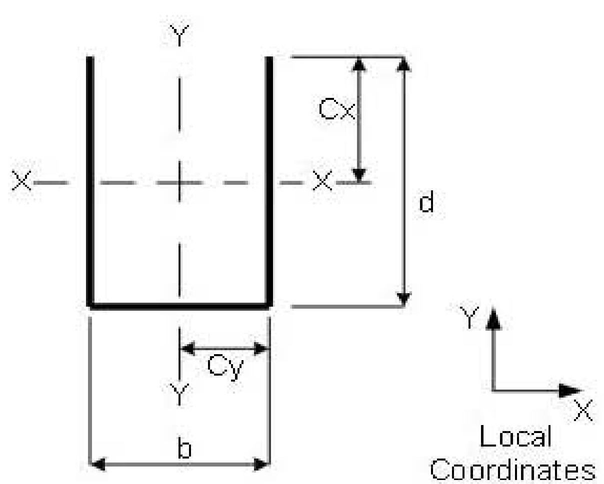
Weld Tensile Stress, S_w = 400.0 MPa (Ref. 3.7)

See the following page for the weld evaluation. Conservatively, the upper section of the pocket is considered to take the full lifting load. The lifting pocket will be seal welded to and bear upon the cask bolting ring. The lifting load will therefore be shared between the lifting pocket weld and the bolting ring. Conservatively, the full load is considered to be taken by the lifting pocket weld only.

The stresses in the welds attaching the lifting pocket to the cask outer shell are found by applying the shear load from the lifting pockets to the weld around the perimeter of the plate. Based on the safety factors for the lifting pocket, yielding will control the weld evaluation. The stresses and allowables are determined as described in Reference 3.3

FILLET WELD EVALUATION: (Blodgett, Design of Welded Structures) (DIN No. 5)

DESCRIPTION: (joint, loading, members, etc.)
Weld Between Lifting Pocket and Cask Body
See Reference 3.2 for weld information



WELD PROPERTIES ARE AS FOLLOWS:

d =	0.21	m
b =	0.30	m
$Sx = bd + d^2/3 =$	0.08	m^3/m
$Sy = bd + b^2/3 =$	0.09	m^3/m
$Cy = b/2 =$	0.15	m
$Cx = d/2 =$	0.11	m
$Aw = 2[b + d] =$	0.72	m
$Jw = (b + d)^3/6 =$	0.02	m^4/m

WELD (EXX) STRENGTH = Fw = 400.0 MPa Weld size = 0.01 m
BASE METAL STRENGTH (FY)= 172.4 MPa Thickness = 0.01 m
(Smaller of weld size or base metal thickness)

LOADING AT CENTER OF PATTERN: (using local coordinate previously defined)

Fx =	0	kN	Mx =	0	kN-m
Fy =	188.8	kN	My =	0	kN-m
Fz =	0	kN	Mz =	0	kN-m

WELD STRESS IS AS FOLLOWS:

$$ft = \frac{Fz}{Aw} + \frac{Mx}{Sx} + \frac{My}{Sy} = \quad 0.00 \quad kN/m \qquad fvy = \frac{Fy}{Aw} + \frac{Mz(Cy)}{Jw} = 262.22 \quad kN/m$$

$$fvx = \frac{Fx}{Aw} + \frac{Mz(Cx)}{Jw} = \quad 0.00 \quad kN/m \qquad fw = (ft^2 + fvx^2 + fvy^2)^{1/2} = \quad 262.22 \quad kN/m$$

Weld Allowable Stress = 0.6(Fw)(Weld Size)(1000)/3 = 800 kN/m
Base Metal Shear Allowable = 0.6(FY) Thick(1000)/0.7071/3 = 488 kN/m
FS FOR WELD METAL STRESS = **3.051** > 1.0 WELD STRESS IS O.K.
FS FOR BASE METAL SHEAR = **1.860** > 1.0 BASE METAL SHEAR IS O.K.

7.8 Failure of Cask Lifting Pockets Under Excessive Loads

The lifting pocket has a factor of safety of 1.86 against lifting eye tear-out and 3.051 against weld failure (see Section 7.7). Therefore, under excessive loading, the failure of the lifting pocket will occur by tear-out of the lifting pocket at the lifting pocket eye or the lifting pocket weld. This will not impair the package's ability to meet other regulatory requirements since the lifting pocket is not integral to the cask body (Ref. 3.2). Tear-out at the lifting pocket eye will only remove the part of the lifting pocket and will not compromise the cask body shell. The same is true if tear-out occurs at the weld rather than in the lifting pocket eye.

Therefore, the RT-100 cask meets the excessive load requirements of Section 71.45(a) of Reference 3.1.

Appendix 1

Cask Design Input Email

Johnathon McFarland

From:	Curt Lindner [clindner@robateltech.com]
Sent:	Friday, July 06, 2012 4:04 PM
To:	John Staples; Johnathon McFarland
Subject:	RT-100 - Maximum Payload and Gross Weights

For the purposes of preparing the lifting, tie-down and bolting analyses, consider a maximum payload weight as 15000 lbs (6820 kg) and a maximum total weight of 41,000 kg (90,200 lbs). These values bound the sum of the maximum gross weight in the procurement agreement and the maximum cask weight of 34054 kg (74,920 lbs) per Robatel drawing RT-100 PE 1001-1, Rev. C.

Curt Lindner
Lead Engineer, Advanced Analysis
ENERCON Excellence—Every project. Every day. | FEDERAL SERVICES, INC.
clindner@enercon.com
office: 770-497-8818 x237
cell: 678-362-7110

Appendix 2

Lifting Ring Design Information

ENERCON Excellence—Every project. Every day.	**CALCULATION CONTROL SHEET** **(Appendix 2)**	**CALC. NO.** RTL- 001-CALC-ST-0201
		REV. 0
		PAGE NO. 2 of 2

norelem Anneau de levage

nlm 07730

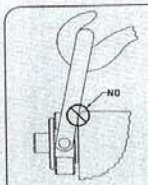
Matière:
Acier de traitement.

Finition:
Bruni.

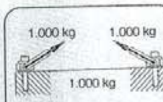
Exemple de commande:
nlm 07730-10

Nota:
Chaque anneau fait l'objet, après le contrôle de charge (coefficient de sécurité 1,5) d'un contrôle visuel. Chaque anneau de levage est accompagné d'une fiche technique de sécurité pour l'installation.
Ne pas utiliser de rondelle ou d'entretoise entre l'anneau et la surface d'appui.
Les vis sont à serrer au couple indiqué. Elles doivent être contrôlées et resserrées à intervalles réguliers. Après le montage, il y a lieu de vérifier si l'anneau pivote librement dans tous les sens.
Soulever avec précaution!
Eviter les chocs!
Ne dépasser sous aucun prétexte la charge admissible poinçonnée sur l'anneau.

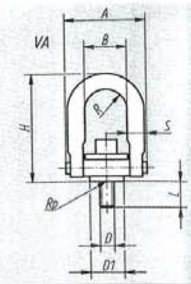
Attention !
N'utilisez en aucun cas des élingues ou autres dispositifs de levage trop grands, qui risqueraient d'écarter l'anneau ou de provoquer l'ouverture de l'arceau en U.



Vérifiez la liberté de rotation / de pivotement de l'anneau dans tous les sens.



Evitez les angles trop aigus. Pour élinguer une charge de 1.000 kg attachée en deux points avec un angle de 30°, chaque suspension doit supporter une charge de 1.000 kg.



Référence Standard	Référence Long	D	D_1	A	B	H Standard	H Long	L	R	S	Charge admis. max. en kg	Couple de serrage M_A (Nm)	kg Standard
07730-08	–	M 8	19,0	46,7	22	67,8	–	12,5	10,9	9,7	400	9,81	0,153
07730-10	–	M10	19,0	46,7	22	67,8	–	17,5	10,9	9,7	450	16,70	0,162
07730-12	07730-112	M12	38,1	89,4	46	121,4	170,7	19,0	22,4	19,0	1050	37,30	1,057
07730-16	07730-116	M16	38,1	89,4	46	121,4	170,7	29,0	22,4	19,0	1900	80,40	1,103
07730-201	07730-1201	M20	38,1	89,4	46	121,4	170,7	34,0	22,4	19,0	2150	133,00	3,112
07730-20	07730-120	M20	58,7	130,6	70	165,6	206,0	32,0	35,6	25,4	3000	133,00	3,112
07730-24	07730-124	M24	58,7	130,6	70	165,6	206,0	37,0	35,6	25,4	4200	304,00	3,203
07730-30	–	M30	81,0	165,1	90	221,7	–	41,9	44,5	31,7	7000	588,00	6,300
07730-36	–	M36	106,4	217,2	115	316,7	–	63,5	57,2	44,4	11000	981,00	15,500
07730-42	–	M42	106,4	217,2	115	316,7	–	68,0	57,2	44,4	12500	981,00	16,000
07730-48	–	M48	106,4	217,2	115	316,7	–	88,0	57,2	44,4	13500	981,00	16,800

norelem Anneau de levage

à revêtement Envirolox®

nlm 0773[illegible]

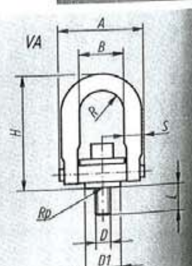
Matière:
Acier de traitement.

Finition:
Anneau: revêtu Envirolox®.
Rondelle: bichromaté.

Exemple de commande:
nlm 07735-10

Nota:
Chaque anneau fait l'objet, après le contrôle de charge (coefficient de sécurité 2) d'un contrôle visuel. Le nouveau revêtement de protection Envirolox® procure une meilleure protection contre les conditions d'environnement sévères. Applications possibles: Atmosphère corrosive, comme p. ex. dans le transport maritime, dans l'industrie chimique etc.

Consignes de sécurité:
voir nlm 07730.



Référence	A	B	D	D_1	H	L	R	S	Charge max. admissible en kg	Couple de serrage M_A (Nm)	kg
07735-08	46,7	22,0	M 8	19,0	67,8	12,5	10,9	9,7	400	9,81	0,153
07735-10	46,7	22,0	M10	19,0	67,8	17,5	10,9	9,7	450	16,70	0,162
07735-12	89,4	46,0	M12	38,1	121,4	19,0	22,4	19,0	1050	37,30	1,057
07735-16	89,4	46,0	M16	38,1	121,4	29,0	22,4	19,0	1900	80,40	1,103
07735-20	89,4	46,0	M20	38,1	121,4	34,0	22,4	19,0	2150	133,00	3,112
07735-120	130,6	70,0	M20	58,7	165,6	32,0	35,6	25,4	3000	133,00	3,112
07735-24	130,6	70,0	M24	58,7	165,6	37,0	35,6	25,4	4200	304,00	3,203
07735-30	165,1	90,0	M30	81,0	221,7	41,9	44,5	31,7	7000	588,00	6,300
07735-130	165,1	90,0	M30	81,0	221,7	61,7	44,5	31,7	7000	588,00	6,350
07735-36	217,2	115,0	M36	106,4	316,7	63,5	57,2	44,4	11000	981,00	15,500
07735-42	217,2	115,0	M42	106,4	316,7	68,0	57,2	44,4	12500	981,00	16,000
07735-48	217,2	115,0	M48	106,4	316,7	88,0	57,2	44,4	13500	981,00	16,800
07735-64	297,6	152,4	M64	146,0	419,1	96,0	76,2	57,2	22500	2845,00	40,000