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ANALIZA UTJECAJA IZVEDBE BRODSKIH CJEVOVODA NA MONTAŽU I RAD PUMPI

ANALYSIS OF THE SHIP PIPING INSTALLATION EFFECT ON THE MOUNTING AND OPERATION OF PUMPS

SAŽETAK

U ovome je radu provedena analiza utjecaja izvedbe brodskih cjevovoda na mogućnost montaže i rada pumpi. Pri ugradnji cjevovoda vrlo se često pojavljuju manja ili veća odstupanja od projektnih dimenzija koja otežavaju montažu opreme poput pumpi, ventila i sl. Naknadne dorade na brodskim cjevovodima neizbježno znače velike dodatne troškove i prekoračenje predviđenog vremena ugradnje cjevovoda. S druge strane, neispravno ugrađena pumpa imat će znatno kraći radni vijek, a ako se kvar na njoj dogodi u nepovoljnom trenutku, posljedice mogu biti ozbiljne. Metodologija kojom se može provjeriti je li izmjereno odstupanje cjevovoda prije ugradnje opreme prihvatljivo, može donijeti znatne uštede pri ugradnji i eksploataciji cjevovoda. Primjenom metode konačnih elemenata moguće je relativno precizno izračunati opterećenja koja djeluju na kućište pumpe pri neispravnoj montaži. U radu je provedena analiza metodom konačnih elemenata na primjeru izabranog segmenta brodskog cjevovoda te su izračunana opterećenja na kućište pumpe kao funkcija veličine odstupanja od projektnih dimenzija. Na temelju dobivenih rezultata može se ocijeniti je li zatečeno odstupanje na realnom cjevovodu prihvatljivo ili ne. U zaključku su dane smjernice za nastavak i sistematizaciju ovog istraživanja prema potrebama i zahtjevima specifičnog tehnološkog procesa izrade i ugradnje cjevovoda.

Ključne riječi: brodski cjevovodi, pumpe, analiza čvrstoće, metoda konačnih elemenata

SUMMARY

In this paper, the analysis of the ship piping installation effect on the possibility of mounting and on the operation of pumps was performed. Smaller or greater deviations from the project dimensions which complicate the mounting of the equipment, such as pumps or valves, appear frequently during the piping installation. Additional works on ship piping inevitably mean high additional costs and overrun of time limits scheduled for the piping installation. On the other hand, incorrectly mounted pump will have significantly shorter working life and if pump malfunction happens in an unfavourable moment, the consequences could be serious. Methodology, by which it could be verified if the measured piping deviation is acceptable before the equipment mounting, could yield in significant savings during the piping installation and exploitation. Loads that affect on the pump housing upon incorrect mounting could be calculated precisely by the application of the finite element method. In this paper, the finite element method analysis was performed on the example of a chosen segment of the ship piping where the pump housing loads were calculated as the function of the piping deviation from the project dimensions. On the basis of the obtained results, it is possible to evaluate whether the pre-existing condition of piping could be acceptable or not. Directives for the continuation and systematization of this research according to the needs and requirements of a specific technological piping production and installation process are given in the conclusion.

Key words: ship piping, pumps, stress analysis, finite element method

1. UVOD

Usporedno s razvojem brodogradnje razvijalo se i cjevarstvo. Smatra se da brodsko cjevarstvo datira od početaka primjene pogonskih strojeva za pogon broda, iako su i najstariji brodovi imali ugrađene jednostavnije cjevovode. Primjenom parnih strojeva, a kasnije i motora s unutarnjim izgaranjem te ostalih strojeva, na brodovima se javila potreba za ugradnjom cjevovoda koji su bili prijeko potrebni za njihov rad. Najprije su se ugrađivali napojni cjevovodi, parno-tlačni cjevovodi, cjevovodi kondenzata, zatim cjevovodi goriva, maziva, rashladne vode itd.

Ugradnjom pogonskih strojeva brodogradnja doživljava pravi procvat. Brodovi postaju sve opremljeniji, međunarodne konvencije i klasifikacijska društva zahtijevaju veću sigurnost brodova na moru, a sve veći broj putnika želi veću udobnost. Sve to dovodi do razvoja raznih brodskih službi s pripadajućim cjevovodima. Tako se na brodovima ugrađuju cjevovodi ka ljuže, cjevovodi balasta, protupožarni cjevovodi, cjevovodi pitke vode, cjevovodi tople i hladne sanitarne vode, izljevni cjevovodi itd. Sve veća automatizacija broskog pogona i sve veće potrebe prijevoza specijalnih tereta uvjetovali su pojavu cjevovoda hidrauličke, cjevovoda rashladnih medija te raznih drugih cjevovoda posebnih namjena [1, 2].

Pumpe i cjevovodi predstavljaju „krvotok” broda i od vitalnog su značaja za plovidbu i eksploataciju broda. Svako odstupanje pri izradi cjevovoda, bilo da je riječ o dimenzijama ili smještaju cjevovoda, dovode do poteškoća pri montaži pumpi te prijevremenog kvara i zastoja pumpi u radu. Servisiranje pumpi ili njihova izmjena tijekom plovidbe nisu lagani i jednostavni zadaci, a mogu biti i rizični za sigurnost posade i broda. Zato je potrebno osigurati uvjete da pumpe i cjevovodi besprijekorno obavljaju svoje funkcije tijekom predviđenoga radnog vijeka, a da se njihova izmjena i remont obavlja u predviđenim terminima tijekom dokovanja i redovitog održavanja brodske opreme.

Odstupanje pri izradi i montaži brodskih cjevovoda česta je pojava i to samo po sebi ne predstavlja nepremostivu prepreku za dovršetak radova. Problem nastaje kada na temelju uočenog odstupanja treba procijeniti smije li se na određenoj dionici cjevovoda ugraditi pumpu ili ne. Ključni podatak za takvu odluku su opte-

1 INTRODUCTION

Piping has been developing in parallel with the development of shipbuilding. It is considered that ship piping dates from the beginning of the use of engines for the ship propulsion, although simple piping was installed on board the oldest ships. By using steam engines and internal combustion engines and other devices afterward, the need for the installation of piping which were necessary for their operation was emerging. The first pipelines were feed water, pressurized steam and condensate pipelines, and thereafter fuel oil, lubricating oil and cooling water pipelines.

With the installation of propulsion engines, shipbuilding experienced a true boom. Ships became more equipped, international conventions and classifying societies required higher safety of ships at sea, while the rising number of passengers wanted a higher comfort. Such development led to the evolution of different ship services with associated piping. Thereby, ships were equipped with piping for bilge, ballast, fire fighting, drinking water, hot and cold fresh water etc. The growing use of automation and the needs for a special cargo transport caused the appearance of hydraulic piping, refrigerant piping and diverse special purpose piping [1, 2].

Pumps and piping represent the ship “blood circulation” and are of vital importance for navigation and ship exploitation. Every deviation during the piping production, whether concerning piping dimensions or location, results with difficulties in the pump mounting and its earlier damage or failure. Pump repair or its replacement during navigation are not easy and simple tasks and could be risky for the safety of the crew and the ship. Therefore, it is necessary to provide conditions in which pumps and piping faultlessly perform their functions during the estimated working life while their replacement and repair are scheduled during docking and regular maintenance of the ship auxiliaries.

Deviations during the ship piping production and installation are common and they do not represent a major problem in work accomplishment. Problems arise in the decision-making process on the mounting of pump on a specific piping segment according to the observed deviations. The key factor for such a decision are loads that occur by forced pump mounting or

rećenja koja nastaju prisilnom ugradnjom pumpe i njenim spajanjem na dijelove cjevovoda koji odstupaju od potrebnih dimenzija. Proračun takvih naprezanja moguće je izvesti čak i za najsloženije cjevovode primjenom odgovarajuće numeričke metode pri čemu je za ovakve slučajeve posebno pogodna metoda konačnih elemenata. U ovome je radu prikazana analiza dionice cjevovoda te su izračunana opterećenja koja bi, ovisno o veličini odstupanja, djelovala na kućište pumpe zbog neodgovarajućeg položaja priključnih pribubnica.

2. SPECIFIČNOSTI UGRADNJE BRODSKIH CJEVOVODA

Brodski cjevovodi služe za provođenje različitih medija brodskih službi kao što su: gorivo, mazivo, morska i slatka voda, komprimirani zrak i razni drugi mediji (freon, inertni plin, hidraulično ulje itd.), čime se omogućuje normalno funkcioniranje glavnog i pomoćnih motora, pumpi, ventilatora, kompresora, izmjenjivača topline i drugih strojnih sustava na brodu.

Projektiranje brodskih cjevovoda danas se u potpunosti provodi s pomoću računala te se na temelju računalnih modela izrađuje cjelokupna radionička dokumentacija. Takva dokumentacija sadrži nacрте u dovoljnom broju pogleda i presjeka za sve cjevovode u teretnom prostoru, strojarnici, nadgrađu, krmi i pramcu, a izrađuje se u principu za nazivne promjere cijevi iznad DN 32 mm [3].

Cjevovodi se vrlo često izrađuju u sklopovima te se kao takve cjeline ugrađuju na brod (Slika 1.). S obzirom na relativno velike dimen-

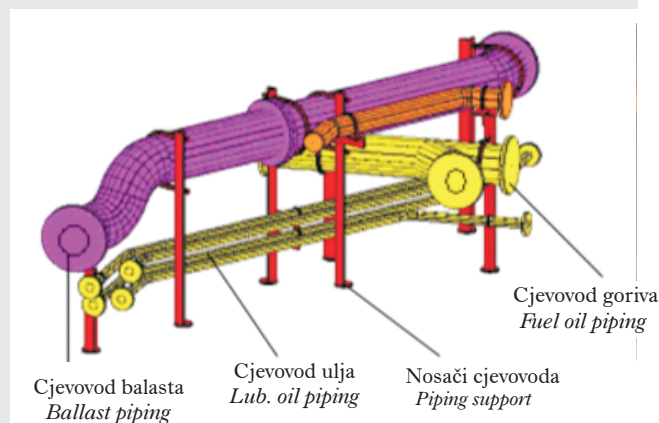
by connecting on pipes that deviate from the required dimensions. The calculation of such loads can be performed even for the most complex piping by applying an adequate numerical method where the finite element method is particularly suitable for those cases. The analysis of the piping section is presented in this paper and loads that affect pump housing due to unmatched position of the connecting flanges are calculated with the dependence on the deviation magnitude.

2 SPECIFICS OF THE SHIP PIPING INSTALLATION

The ship piping systems are used for the transport of different fluids in ship services such as: fuel oil, lubricating oil, seawater and fresh water, compressed air and other different fluids (refrigerants, inert gas, hydraulic oil etc.) thus providing a normal operation of the main and auxiliary engines, pumps, fans, compressors, heat exchangers and other devices.

Nowadays, the design of ship piping is completely performed by computers and a complete manufacturing documentation is made according to the computer models. Such documentation contains drafts with an adequate number of views and sections for all piping in the cargo space, engine room, ship superstructure, fore and aft peaks and it is usually made for pipes over DN 32 mm [3].

Piping is frequently made in assemblies and as such the units are installed on board a ship (Figure 1). Regarding relatively large dimensions and technological processes in manufac-



Slika 1. Primjer CAD modela sklopa cjevovoda i gotov sklop spreman za ugradnju na brod [3]
Figure 1 Example of the CAD model piping assembly and of an assembly ready for installation on board a ship [3]

zije i tehnološke postupke pri izradi koji uključuju plastično deformiranje i značajan unos topline, mogu se očekivati odstupanja od dimenzija predviđenih projektom. Dijelovi koji će biti spojeni s uređajima ili strojevima poput pumpi trebaju biti ugrađeni s odgovarajućim tolerancijama kako bi se osigurala njihova ispravna montaža i pouzdan rad.

3. SPAJANJE PUMPE S CJEVOVODOM

Pumpe su neophodni dio opreme u gotovo svim brodskim sustavima. U uporabi su najčešće centrifugalne pumpe koje udovoljavaju zahtjevima koje mora ispuniti određeni brodski sustav. Sastoje se od spiralnog kućišta i rotora pričvršćenog na vratilu. Na slici 2. prikazana je vertikalna centrifugalna pumpa kakve se često ugrađuju u brodskim sustavima.

Kućiste je opremljeno prirubnicama na ulaznom i izlaznom otvoru kojima se pumpa pričvršćuje na cjevovod. Na slici 3. prikazan je mogući položaj pumpe u odnosu na cjevovod opisan veličinama A, B, C i D. Veličina varijabli A, B, C i D može biti pozitivna ili negativna te su neovisne jedna o drugoj. Uzroci pojavljivanja ovakvih odstupanja pri montaži cjevovoda mogu biti nepreciznost pri izradi dijelova, nepreciznost pri zavarivanju dijelova i prirubnica,

turing which include plastic deforming and considerable heat input, deviations from the project dimensions could be expected. Parts which are going to be connected with devices like pumps should be installed with adequate tolerances in order to provide their correct mounting and reliable operation.

3 CONNECTING A PUMP WITH A PIPELINE

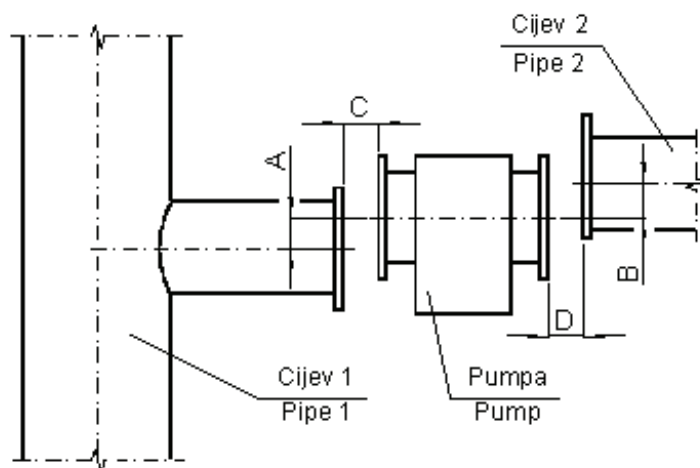
Pumps are an inevitable part of the equipment in almost all ship systems. The most frequently used pumps are centrifugal pumps and they comply with the requests which are set to certain ship systems. They consist of the spiral housing and of an impeller fixed on the rotating shaft. An example of vertical centrifugal pumps which are frequently used on board ships is shown in Figure 2.

The pump housing has flanges on inlet and outlet ports which are used for connecting a pump with the pipeline. Figure 3 shows the possible pump position regarding the pipeline described by values A, B, C and D. Values A, B, C and D could be positive or negative and they are independent of each other. Such deviations can be the consequence of inaccuracy during part production, inaccuracy upon welding pipes and flanges, deformations due



Slika 2. Vertikalna centrifugalna pumpa
Figure 2 Vertical centrifugal pump

Izvor / Source: <http://www.croatia-pumpe.com/hr>



Slika 3. Položaj pumpe u odnosu na cjevovod
Figure 3 Pump position relating to piping

Izvor / Source: Autori / Authors

deformacije zbog unosa topline, nepravilno postavljene oslonci cjevovoda itd.

Ovi pomaci u praksi nisu veliki i pumpa se u nekim slučajevima može montirati na cjevovod uporabom pomoćnih sredstava (poluga, ručna hidraulična preša, kolotur s lancem i sl.) kojima se cjevovod privremeno elastično deformira, kako bi se provrtili na prirubnicama doveli u položaj pogodan za umetanje priteznih vijaka. Ovisno o veličini cjevovoda, materijalu od kojega je izrađen, načinu pričvršćenja i ostalim relevantnim čimbenicima, sile koje je potrebno primijeniti za takve zahvate mogu biti relativno velike. Uklanjanjem pomoćnih sredstava kojima je cjevovod bio privremeno elastično deformiran, kućište pumpe preuzima preko prirubnica opterećenja koja su do tada djelovala na cjevovod. Kao posljedica takve montaže pumpe, u radu se mogu pojaviti različite poteškoće pa čak i trajna oštećenja pumpi.

4. PRIMJER ANALIZE DIONICE BRODSKOG CJEVOVODA

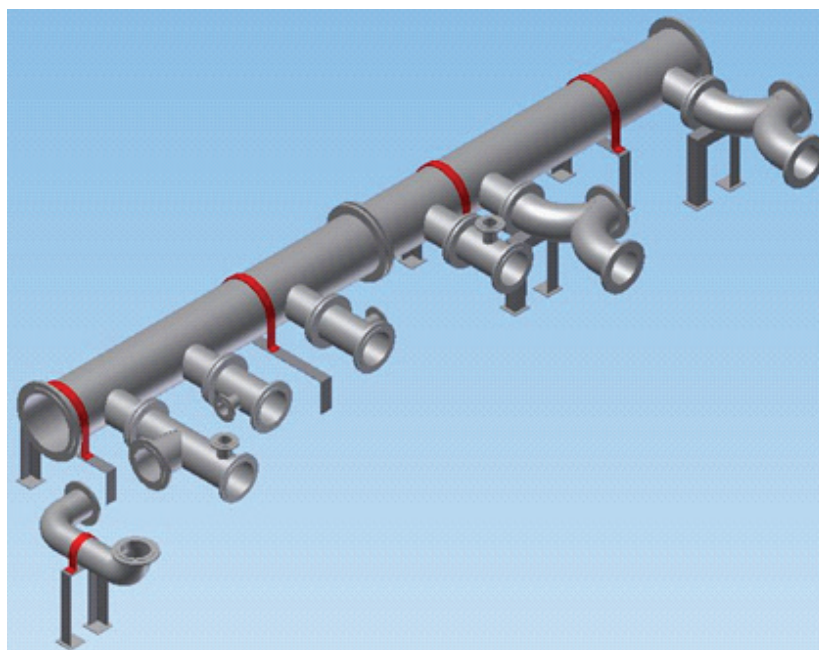
U ovome je radu analiziran primjer dionice broskog cjevovoda za usis morske vode na kojemu se nalazi više ogranaka spojenih s odgovarajućim pumpama. Model dionice cjevovoda prikazan je na slici 4. te se može uočiti da se sastoji od dviju cijevi većeg promjera na koje je spojen veći broj ogranaka manjeg promjera.

to heat input, irregularly mounted supports etc.

In practice, these deformations are not great and in some cases the pump can be mounted on the piping by the use of improvised equipment (lever, hand hydraulic press, chain hoists etc) by which the piping can be temporarily elastically deformed so holes on flanges align in the position suitable for bolts inserting. Depending on the piping size, its material, fixing and other relevant factors, forces for such intervention could be relatively great. By removing the improvised equipment used for the temporary piping deformation, the pump housing takes over the load that was previously acting on the piping. As a consequence of such a pump mounting, different problems or even permanent damage could occur during the pump exploitation.

4 EXAMPLE OF THE SHIP PIPING SECTION ANALYSIS

In this paper, a section of the ship piping for sea water suction with several branches connected to adequate pumps was analyzed. The model of the piping segment is shown in Figure 4 and it is clearly visible that the piping consists of several branches of a smaller diameter connected to two pipes of a larger diameter.

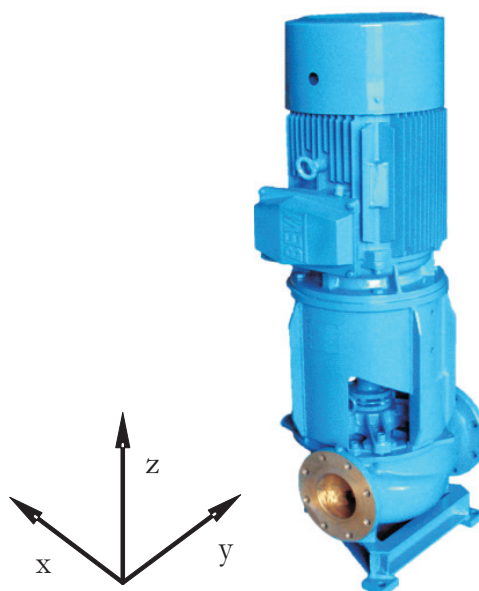


Slika 4. Model dionice cjevovoda
Figure 4 A piping segment model

Izvor / Source: Autori / Authors

Analizom će biti obuhvaćen jedan od ograna-
naka na kojem je ugrađena centrifugalna pum-
pa, oznake CGB 100 V48 (Slika 5.) s nominal-
nom veličinom prirubnice DN 100, proizvođača

The analysis covered one of the branches on
which a centrifugal pump of the type CGB 100
V48 (Figure 5) is fitted, with a nominal
size of DN 100, produced by *Croatia Pumpe*



Slika 5. Jednostupanjska centrifugalna pumpa CGB 100V48 s pripadajućim koordinatnim sustavom prema
API 610 standardu

*Figure 5 One-stage CGB 100V48 centrifugal pump with the associated coordinate system according to the
API 610 standard*

Izvor / Source: <http://www.croatia-pumpe.com/hr>

Croatiapumpe d.d. Pumpa se na postolje spaja s pomoću triju vijaka.

Prema uputama proizvođača, pri spajanju pumpe na cjevovod treba paziti na razmak između osi cjevovoda i osi pumpe, koji ne smije biti veći od onoga pri kojem vijak može nesmetano proći kroz prirubnice. Također, treba voditi računa da površine prirubnica budu razmaknute toliko da se pri montaži između njih može uvući predviđena brtva. Površina na koju se montira pumpa treba biti dobro ukrućena, kako ne bi došlo do pojave vibracija tijekom normalnog rada pumpe.

Kako bi se preventivno spriječili problemi u radu, proizvođač pumpi zahtijeva da se pri montaži pumpe poštuju vrijednosti propisane standardom API 610 [4]. U ovome su standardu sadržane informacije o zahtjevima kojima mora udovoljavati pumpa kao i o silama i momentima koji se smiju pojaviti na prirubnicama na kućištu pumpe. U tablici 1. navedene su vrijednosti sila i momenata na prirubnicama pumpe ovisno o nominalnoj veličini prirubnica.

Nova d.d. The pump is fitted on the support with three bolts.

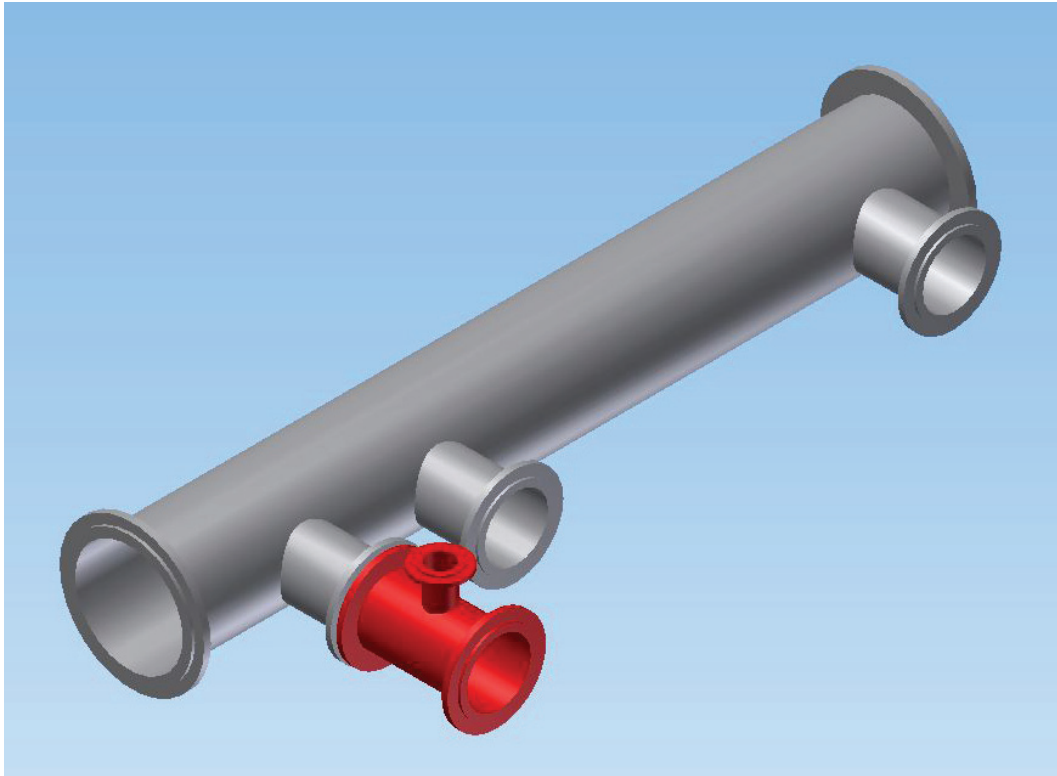
According to the producer's instructions, the misalignment between the pump and the piping axes can be so large that the bolt can easily pass through the holes on the flanges when connecting the pump with the pipeline flange. Furthermore, the flange surfaces should be spaced so much to enable the gasket to be placed between them during the pump mounting. The support surface for the pump mounting should be sufficiently rigid to prevent vibrations during the normal pump running.

To prevent problems during the pump running, the pump producer requests that the propositions prescribed by the API 610 standard [4] must be complied with during the pump mounting. This standard contains information on the requirements for pumps as well as for forces and moments which might occur on pump connecting flanges. The values of forces and moments on pump flanges, depending on the nominal flange size, are given in Table 1.

Tablica 1. Dopuštena opterećenja prirubnica pumpi prema API 610 standardu [4]

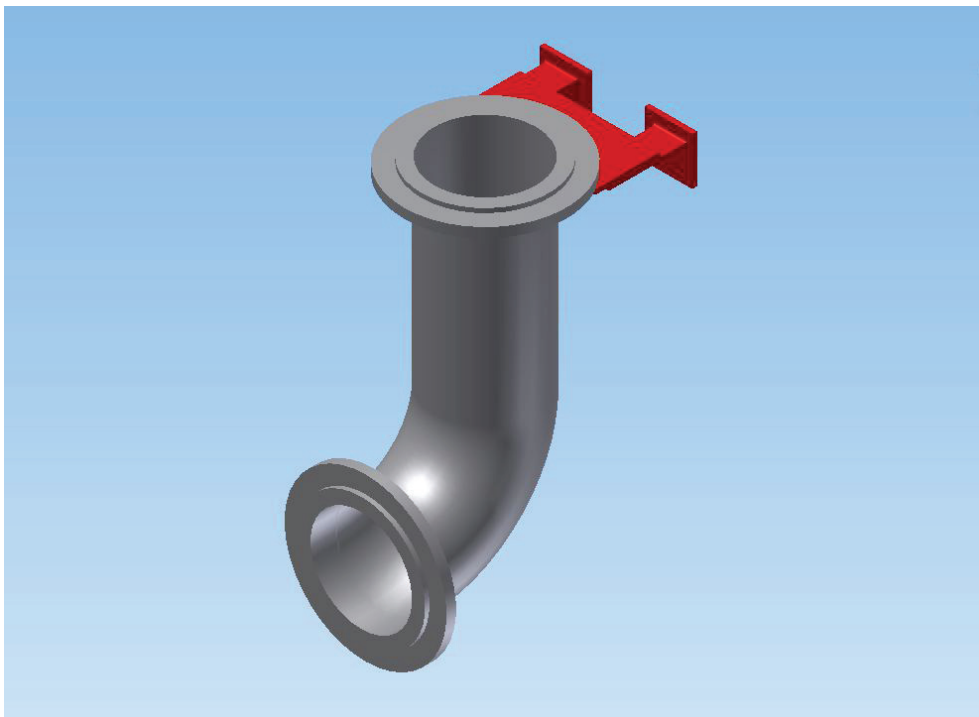
Table 1 Allowed loads on pump connecting flanges according to the API 610 standard [4]

Sila / Moment	Nominalna veličina prirubnice, mm / Nominal flange size, mm								
	DN 50	DN 80	DN 100	DN 150	DN 200	DN 250	DN 300	DN 350	DN 400
Dopuštene vrijednosti sila na gornjim prirubnicama pumpe <i>Allowed values of forces on pump top flanges</i>									
F_{X^2} , N	712	1068	1423	2491	3781	5338	6672	7117	8452
F_{Y^2} , N	890	1334	1779	3114	4893	6672	8007	8896	10231
F_{Z^2} , N	578	890	1157	2046	3114	4448	5338	5783	6672
F_{R^2} , N	1290	1913	2535	4493	6939	9786	11565	12900	15569
Dopuštene vrijednosti sila na bočnim prirubnicama pumpe <i>Allowed values of forces on pump side flanges</i>									
F_{X^2} , N	712	1068	1423	2491	3781	5338	6672	7117	8452
F_{Y^2} , N	578	890	1157	2046	3114	4448	5338	5783	6672
F_{Z^2} , N	890	1334	1779	3114	4893	6672	8007	8896	10231
F_{R^2} , N	1290	1913	2535	4493	6939	9786	11565	12900	13345
Dopuštene vrijednosti sila na izlaznim prirubnicama pumpe <i>Allowed values of forces on pump exit flanges</i>									
F_{X^2} , N	890	1334	1779	3114	4893	6672	8007	8896	10231
F_{Y^2} , N	578	890	1157	2046	3114	4448	5338	5783	6672
F_{Z^2} , N	712	1068	1423	2491	3781	5338	6672	7117	8452
F_{R^2} , N	1290	1913	2535	4493	6939	9786	11565	12900	14679
Dopuštene vrijednosti momenata na prirubnicama pumpe <i>Allowed values of moments on pump flanges</i>									
M_{X^2} , Nm	461	949	1329	2305	3525	5016	6101	6372	7321
M_{Y^2} , Nm	353	719	1003	1763	2576	3796	4610	4745	5423
M_{Z^2} , Nm	230	475	678	1180	1763	2440	2983	3118	3661
M_{R^2} , Nm	624	1288	1803	3132	4745	6779	8270	8542	9762



Slika 6. Model cijevi 1
Figure 6 Model of pipe 1

Izvor / Source: Autori / Authors



Slika 7. Model cijevi 2
Figure 7 Model of pipe 2

Izvor / Source: Autori / Authors

Pumpe s veličinom prirubnice DN 400 (16") i manje, s kućištem izrađenim od čelika trebale bi moći izvršavati svoju zadaću pri opterećenjima prikazanim u tablici 1.

Isti standard propisuje i orijentaciju koordinatnog sustava za pojedinu izvedbu kućišta prema kojemu se uspoređuju vrijednosti u gore navedenoj tablici. Na slici 5. prikazana je centrifugalna pumpa tip CGB 100V48 s pripadajućim koordinatnim sustavom. Prema API standardu, za ovu izvedbu kućišta pumpe vrijednosti u tablici 1. potrebno je pomnožiti faktorom 2.

Za potrebe ove analize, dionica cjevovoda prikazana na slici 4. podijeljena je na manje cjevine. Dio cjevovoda ispred pumpe se sastoji od veće cijevi i manje cijevi na koju se spaja pumpa (Slika 6.). Cijeli sklop bit će u daljnjem tekstu nazivan cijev 1. Na slici 7. prikazan je drugi dio cjevovoda koji se nastavlja na pumpu. Taj dio cjevovoda čvrsto je zavaren na pregradu strojarnice jer se na njega nadovezuje cjevovod koji se vertikalno diže na gornju razinu strojarnice. Nosač ovoga dijela cjevovoda preuzima težinu ostalih cijevi koje se nadovezuju u vertikalnom smjeru. Ova cijev je u daljnjem tekstu nazvana cijev 2.

Tijekom montaže ovih dijelova cjevovoda može doći do odstupanja položaja osi simetrije prirubnica koje se pričvršćuju na pumpu. Ako su ta odstupanja relativno mala, a vijci se ne mogu provući kroz provrte u prirubnicama, potrebno je odlučiti na koji će se način pristupiti montaži pumpi: elastičnim deformiranjem cjevovoda ili demontažom dijela cjevovoda i naknadnom doradom. Ako bi za elastično deformiranje cjevovoda bile potrebne sile koje su manje od sila dopuštenih standardom API 610, takvim bi se postupkom uštedjela znatna sredstva potrebna za demontažu i naknadnu obradu cjevovoda. U suprotnom, ako je kućište pumpe opterećeno silama većim od standardom dopuštenih, može doći do smetnji u radu pumpe, njenog otkazivanja, a u najgorem slučaju trajnim oštećenjem. Proračunom sila i momenata koji nastaju elastičnim deformiranjem cjevovoda može se doći do saznanja kolika su najveća dopuštena odstupanja, a pri kojima se montažom neće premašiti vrijednosti propisane standardom.

Proračun sila i momenata proveden je uporabom metode konačnih elemenata i računalnog programskog paketa Autodesk Inventor [5]. S pomoću istoga alata izrađen je trodimenzional-

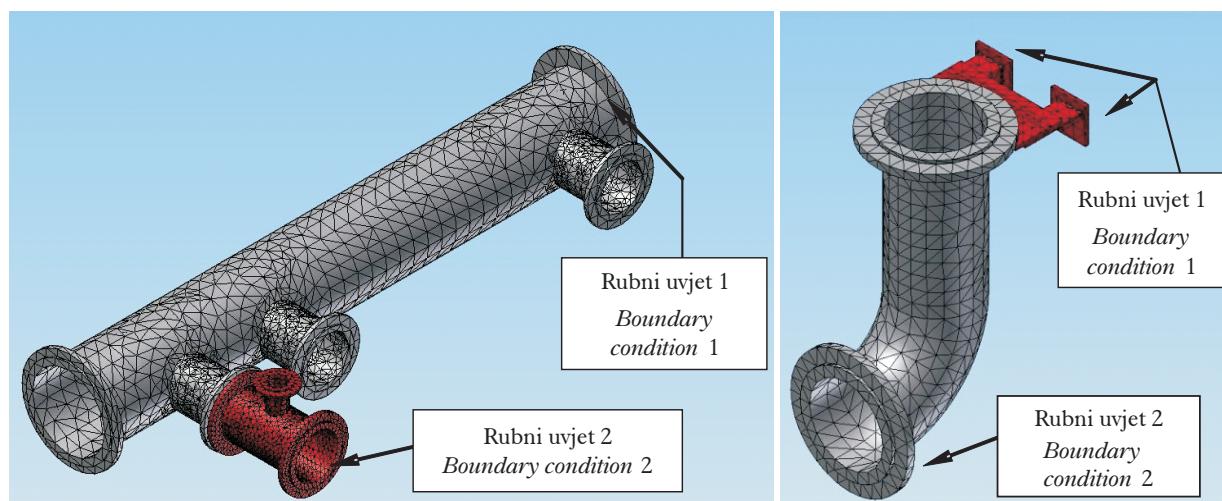
Pumps with flange size DN 400 (16") and less, with housing made of steel should be able to work normally under loads shown in Table 1.

The same standard regulates the orientation of the coordinate system for a particular housing construction which is the reference for values referred to in the above-mentioned table. The centrifugal pump of the CGB 100V48 type with the associated coordinate system is shown in Figure 5. According to the API 610 standard, the values from Table 1 should be multiplied by factor 2 for this pump housing construction.

For the purpose of this analysis, the piping segment shown in Figure 4 was divided into smaller parts. The part of the piping in front of the pump consists of a larger and of a smaller pipe connected with the pump (Figure 6). The whole assembly will be named as pipe 1 in the following text. The other part of the piping that continues after the pump is shown in Figure 7. That part of the piping is rigidly welded on the engine room bulkhead because it is connected with the piping that is rising vertically on the upper deck of the engine room. The support of this piping segment holds the weight of other pipes which are added in a vertical direction. This pipe is named pipe 2 in the following text.

The misalignments of flanges that are connected with the pump might occur during the installation of those parts of the piping. If those misalignments are relatively small and bolts cannot pass through the holes in the flanges, it is necessary to decide what method of the pump mounting will be used: an elastic deformation of the piping or the dismantling of the piping segment and an additional processing. If the elastic deformation of the piping requests forces that are smaller than forces allowed by the API 610 standard, such a procedure would save considerable resources for dismantling and additional pipes processing. On the contrary, if the pump housing is loaded with forces higher than allowed by the standard, problems during pump running or permanent damages might occur. By calculating the forces and the moments which occur under elastic piping deformation, it is possible to find out which are the maximum allowable deviations where the values prescribed by the standard will not be exceeded.

The calculation of the forces and moments was performed by a finite element method and by the Autodesk Inventor computer software



Slika 8. Mreže konačnih elemenata na analiziranim dijelovima cjevovoda
Figure 8 Finite element meshes on the analyzed piping segments

Izvor / Source: Autori / Authors

ni model cjevovoda prikazan na slici 4., a njegovi segmenti koji su detaljno analizirani, omreženi su mrežom konačnih elemenata i pripremljeni za analizu, slika 8.

U modelu su korištene dvije vrste rubnih uvjeta pri čemu rubni uvjet 1 predstavlja uklještenje, dok je rubni uvjet 2 narinuti pomak u željenom smjeru. Vijčani spojevi prirubnica analiziranih cijevi modelirani su zbog jednostavnosti kao krute veze. U ovim primjerima analizom nije bio obuhvaćen utjecaj oslonaca cjevovoda što utječe na krutost cijele dionice cjevovoda. Utjecaj toplinskih dilatacija zbog zagrijavanja cjevovoda nije uzet u obzir jer se radi o cjevovodu za usis morske vode čija temperatura ne odstupa značajnije od temperature okoline. Modeli cijevi omreženi su nestrukturiranom mrežom trodimenzionalnih konačnih elemenata pri čemu su korišteni tetraedarski elementi drugoga reda [6].

4.1. Analiza rezultata – cijev 1

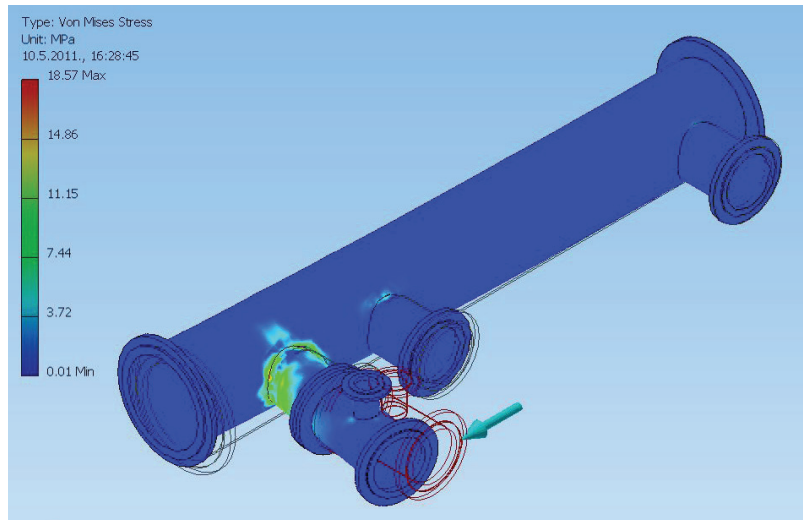
Analiza je provedena na način da su na slobodnim krajevima prirubnica, odnosno na mjestu rubnog uvjeta 2, narinuti pomaci u smjerovima osi x i z . Pomaci su varirani u rasponu od 0 do 4 mm s koracima od 0,5 mm. Prikaz ekvivalentnih naprežanja na modelu cijevi 1 za pomak od 1 mm u smjeru osi z prikazan je na slici 9., dok su veličine sila i momenata na prirubnici za sve ostale pomake prikazani u dijagramima na slici 10.

[5]. The same software was used for building a three dimensional model of piping shown in Figure 4 and its segments were meshed with finite elements meshes and prepared for analysis (Figure 8).

Two types of boundary conditions were used in the model where the boundary condition 1 represents clamping while boundary condition 2 represents displacement in the chosen direction. Due to simplicity, the bolted joints of the piping flanges are modelled as rigid connections. The influence of the piping supports was not included in this analysis what affects on the stiffness of the whole analyzed piping segment. Thermal dilatations due to the piping heating or cooling were not taken into account because the analyzed piping deals with the seawater suction and its temperature does not significantly differ from the ambient temperature. The pipe models are meshed with an unstructured mesh of three dimensional elements where the tetrahedral finite elements of the second order were used [6].

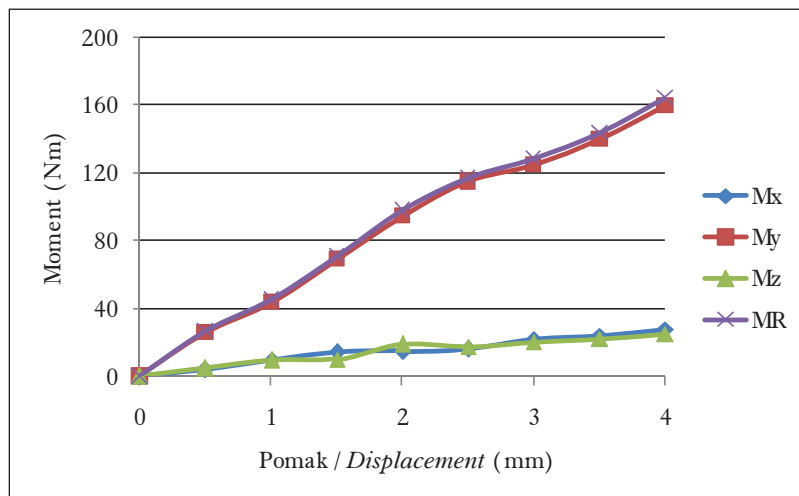
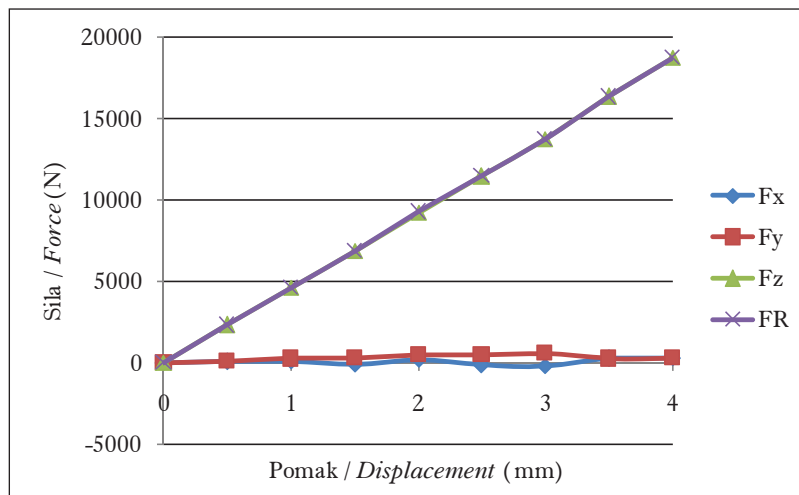
4.1 Results analysis – Pipe 1

The analysis is performed in a way that the free end of the flange or the boundary condition 2 position were set with the displacements in the directions of the x and z axes. The displacements varied in range from 0 to 4 mm in steps of 0.5 mm. The equivalent stresses on the model of the pipe 1 for displacement of 1 mm



Slika 9. Model cijevi 1 – naprezanja u segmentu cjevovoda kao posljedica pomaka na prirubnici
Figure 9 Model of pipe 1 – stresses in the piping segment as a result of the flange displacement

Izvor / Source: Autori / Authors



Slika 10. Ovisnost sila i momenata o veličini odstupanja prirubnice u smjeru osi z – cijev 1
Figure 10 Dependence of the forces and the moments on flange deviation in the direction of the z axis – pipe 1

Izvor / Source: Autori / Authors

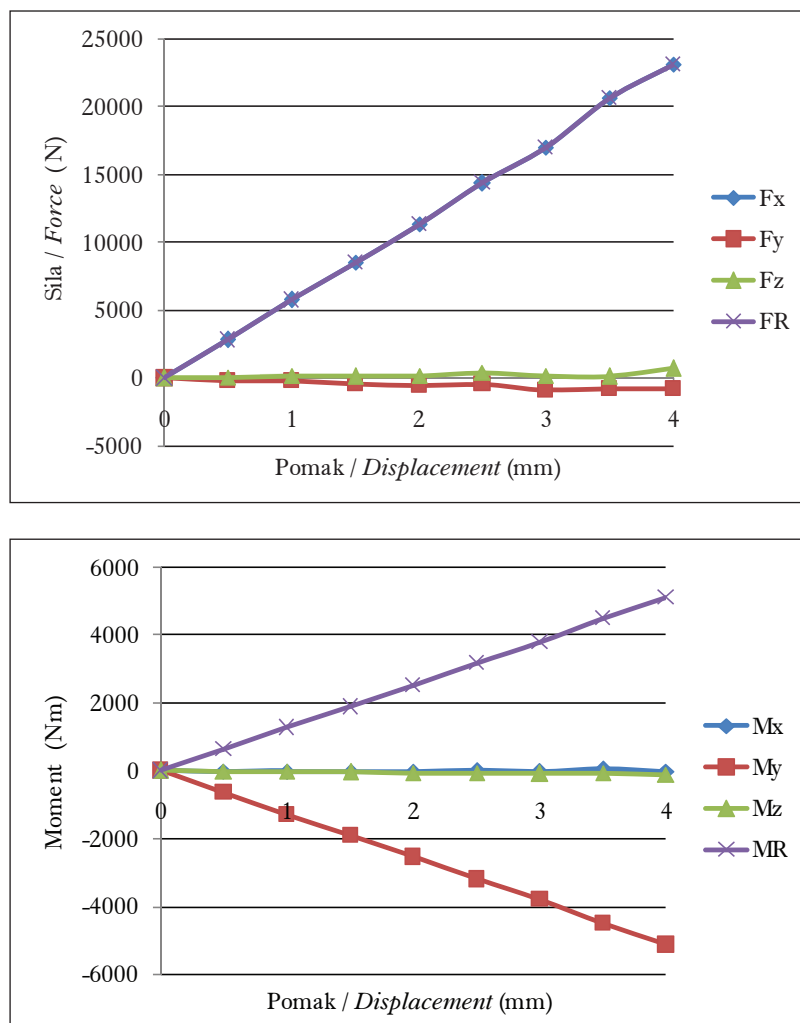
Iz dobivenih se rezultata može zaključiti da odstupanje pri montaži pumpe u smjeru osi z ne smije biti veće od 0,5 mm jer će to izazvati opterećenje na kućište pumpe iznad standardom propisanih vrijednosti. Ovaj dio analize proveden je samo za odstupanje u smjeru osi z, dok su odstupanja u drugim smjerovima jednaka nuli.

Na slici 11. prikazani su rezultati za slučaj kada je prirubnica analizirane cijevi pomaknuta u smjeru osi x. Analizirani su slučajevi za pomak od 0 do 4 mm u koracima od po 0,5 mm, identično kao i u prethodnom slučaju. Veličina sila i momenata koji se u ovome slučaju pojavljuju ukazuju da odstupanje položaja prirubnice ne bi smjelo biti veće od 0,5 mm u smjeru osi x ako se poštuju zahtjevi propisani standardom API 610 [7].

in the direction of the z axis is shown in Figure 9, while values of the forces and moments on the pipe flange for the whole range of displacements are shown on graphs in Figure 10.

According to the obtained results, it can be concluded that the deviation in the direction of the z axis must not exceed 0.5 mm during the pump mounting, because loads on the pump housing will be higher than the values prescribed by the standard. This part of the analysis is performed only for the deviation in the direction of the z axis, while deviations in other directions were equal to zero.

The results for the case of the flange deviation in the direction of the x axis are shown in Figure 11. The analyzed cases are for the displacement from 0 to 4 mm in steps of 0.5 mm,



Slika 11. Ovisnost sila i momenata o veličini odstupanja prirubnice u smjeru osi x – cijev 1
Figure 11 Dependence of the forces and the moments on flange deviation in the direction of the x axis – pipe 1

Izvor / Source: Autori / Authors

4.2. Analiza rezultata – cijev 2

Ovaj dio analize odnosi se na cijev 2 koja se spaja na izlaznu priрубnicu pumpe. Na isti način kao i u prethodnom slučaju, odstupanje priрубnice povećavano je od 0 do 4 mm u koracima od po 0,5 mm. Istražen je utjecaj odstupanja priрубnice zasebno po osi x, zasebno po osi z i istodobno po osima x i z.

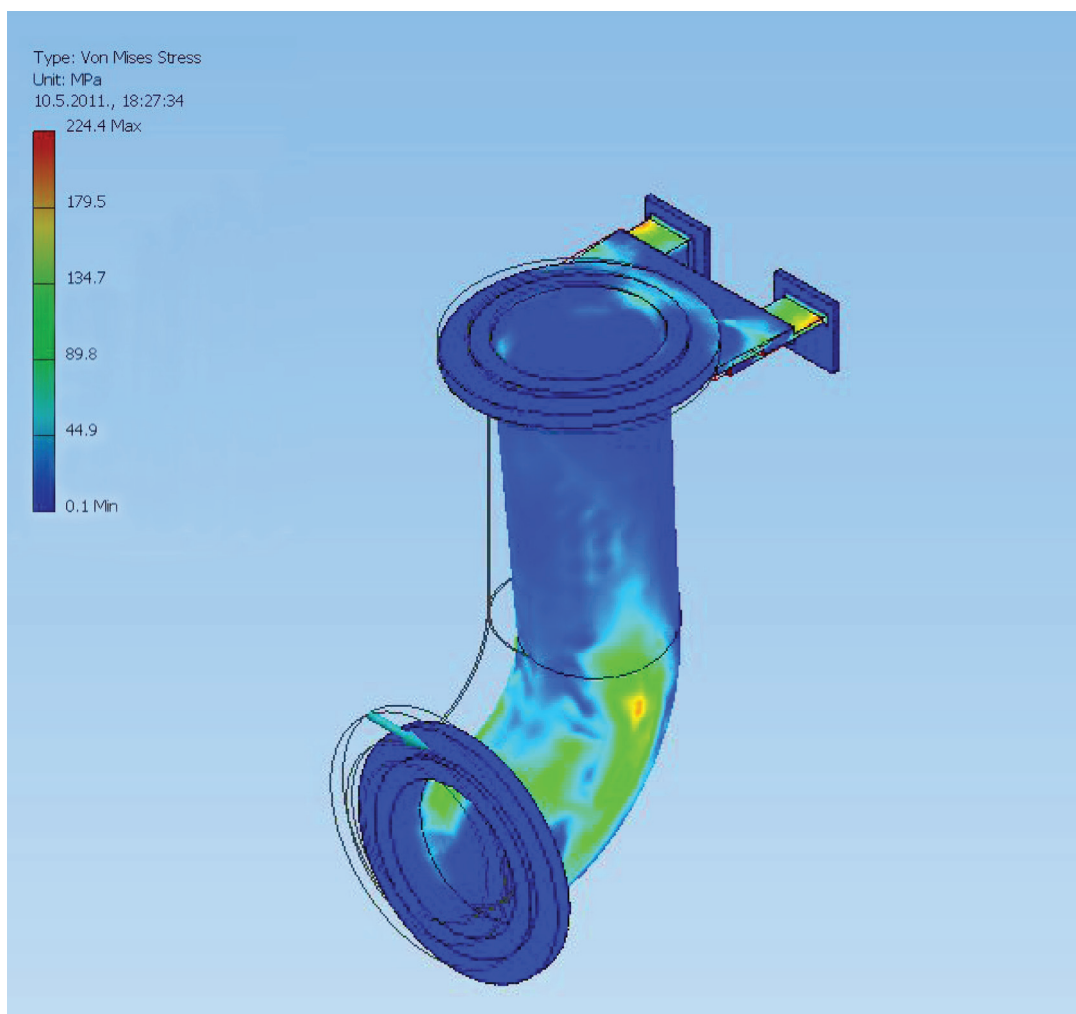
Prikaz ekvivalentnih naprezanja na modelu cijevi 2 za pomak od 4 mm u smjeru osi x prikazan je na slici 12., dok su na slici 13. prikazane promjene sila i momenata koji se pojavljuju na priрубnici pumpe ovisno o veličini odstupanja u smjeru osi x. Rezultati dobiveni zbog odstupanja u smjeru osi z prikazani su na slici 14., a na slici 15. prikazani su rezultati za istodobno odstupanje položaja priрубnice u smjeru osi x i z.

identically as in the previous example. The values of the forces and the moments which occur in this case indicate that the flange deviation must not be greater than 0.5 mm in the direction of the x axis if the requirements of the API 610 standard are followed [7].

4.2 Results analysis – Pipe 2

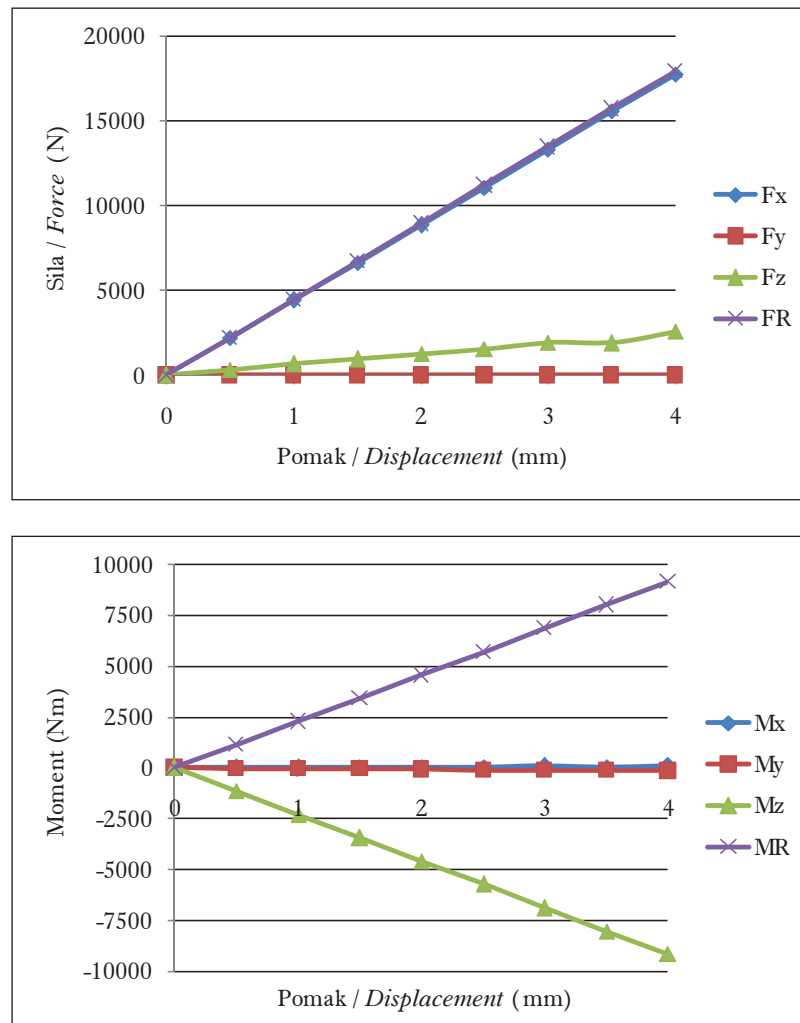
This part of the analysis refers to pipe 2 which is connected on the exit pump flange. In the same way as in the previous example, the flange deviation is altered from 0 to 4 mm in the steps of 0.5 mm. The influence of the flange deviation is analyzed separately for directions of the x axis, z axis and x and z axes simultaneously.

The equivalent stresses on the pipe 2 model for the displacement of 4 mm in the direction



Slika 12. Model cijevi 2 – naprezanja u segmentu cjevovoda kao posljedica pomaka na priрубnici
Figure 12 Model of pipe 2 – stresses in the piping segment as the result of the flange displacement

Izvor / Source: Autori / Authors



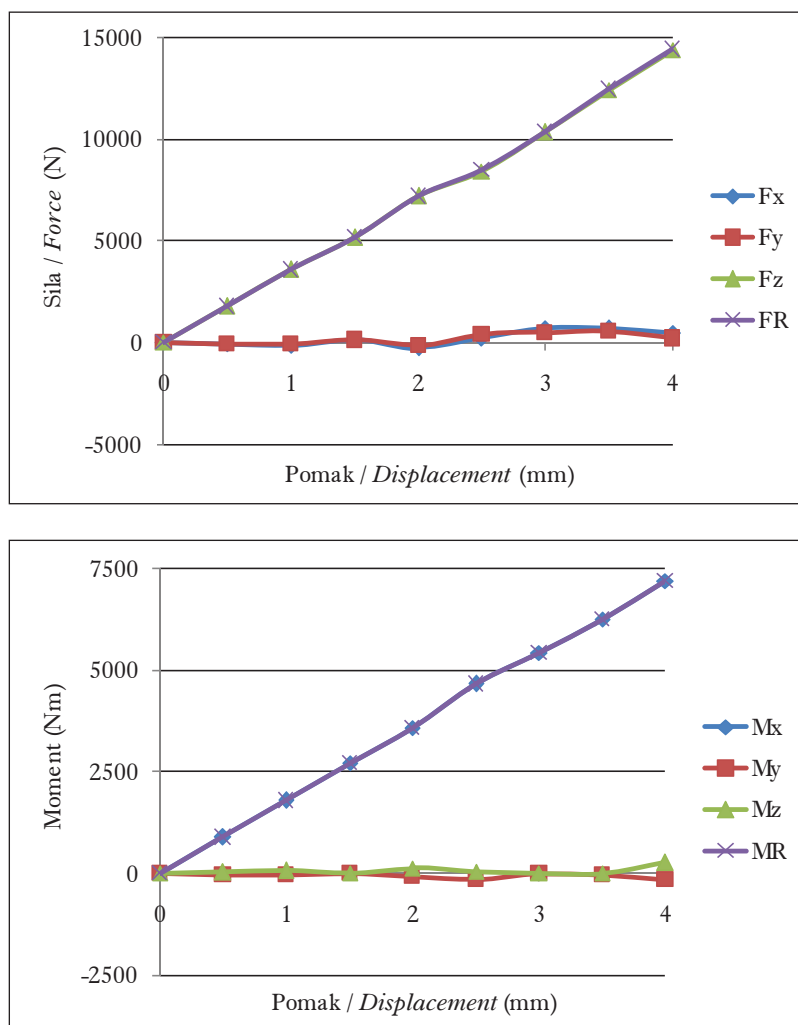
Slika 13. Ovisnost sila i momenata o veličini odstupanja prirubnice u smjeru osi x – cijev 2
Figure 13 Dependence of the forces and the moments on the flange deviation in the direction of the x axis – pipe 2

Izvor / Source: Autori / Authors

Na temelju dobivenih rezultata može se zaključiti da se pumpa može montirati ako su odstupanja u smjeru osi x ili u smjeru osi z veličine 0,5 mm ili manja. U slučaju kada se odstupanja istodobno pojavljuju u smjerovima osi x i z, opterećenja na kućište pumpe s nominalnom veličinom prirubnice DN 100 bila bi prevelika čak i za odstupanje od 0,5 mm.

of the x axis are shown in Figure 12, while the forces and the moments which occur on the pipe flange depending on the deviation in the direction of the x axis are shown in Figure 13. The results obtained due to deviations in the direction of the z axis are shown in Figure 14, while the results for the simultaneous deviation in the direction of the x and z axes are shown in Figure 15.

On the basis of the obtained results, it can be concluded that a pump can be mounted if the deviations in the direction of the x axis or in the direction of the z axis are 0.5 mm or less. In the case when the deviations occur simultaneously in the directions of the x and z axes, the loads on the pump housing with a nominal flange size DN 100 would be too high even for the deviation of 0.5 mm.



Slika 14. Ovisnost sila i momenata o veličini odstupanja prirubnice u smjeru osi z – cijev 2
Figure 14 Dependence of the forces and the moments on the flange deviation in direction of the z axis – pipe 2

Izvor / Source: Autori / Authors

5. ZAKLJUČAK

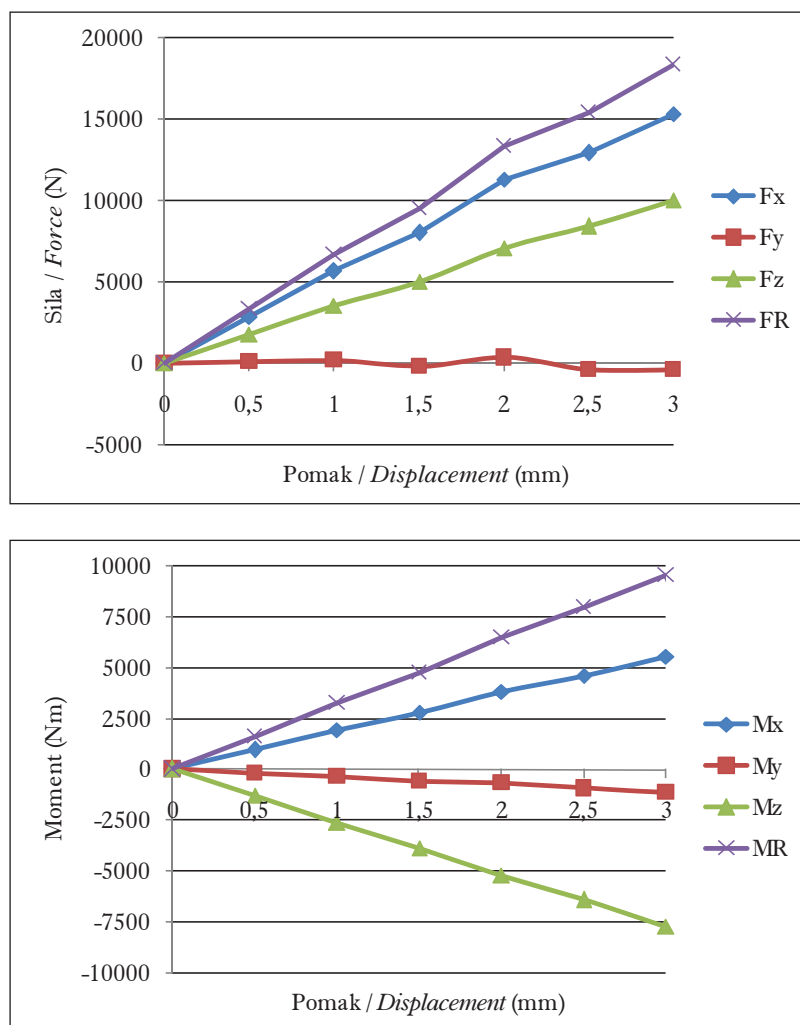
U ovome je radu provedena analiza utjecaja izvedbe brodskih cjevovoda na mogućnost montaže i rada pumpi. Prikazane su problematika i specifičnosti ugradnje takvih instalacija u brodskim postrojenjima. Odstupanja pri ugradnji cjevovoda nisu rijetka pojava, što je sasvim razumljivo ako se u obzir uzmu razni utjecajni čimbenici poput tehnologije izrade, primijenjenih postupaka spajanja, radnih uvjeta na brodu i sl. Na temelju izmjerena odstupanja teško je procijeniti hoće li montaža pumpe uz elastično deformiranje cjevovoda uzrokovati prevelika opterećenja kućišta pumpe.

Primjenom metode konačnih elemenata moguće je relativno precizno izračunati opterećenja koja nastaju u gore navedenom slučaju te

5 CONCLUSION

In this paper, the analysis of the ship piping installation effect on the mounting and operation of pumps was carried out. The problems and specifics of the piping installation within the ship systems are presented. Deviations in the piping installation are common, what is reasonable if different factors are taken into account like production technology, applied methods of joining, working conditions on board a ship etc. On the basis of the measured deviation, it is difficult to evaluate if the pump mounting with an elastic deformation of the piping will cause too high loads of the pump housing.

Loads that affect on the pump housing upon incorrect mounting could be calculated precise-



Slika 15. Ovisnost sila i momenata o veličini odstupanja prirubnice u smjeru osi x i z – cijev 2
Figure 15 Dependence of the forces and the moments on the flange deviation in the direction of the x and z axes – pipe 2

Izvor / Source: Autori / Authors

se lako može donijeti ispravna odluka je li izmjereno odstupanje prihvatljivo ili nije. Rezultati dobiveni analizom prikazanoga primjera ukazuju da vrlo mala odstupanja mogu uzrokovati preveliko naprezanje u kućištu pumpe ako se ona montira na nepravilan način.

Analiza provedena u ovome radu otvara dodatna pitanja i nepoznanica koje autori još namjeravaju istražiti. Krajnji cilj takvog istraživanja je izrada baze znanja u kojoj bi bili sadržani podaci o mogućnosti montaže pumpi i druge opreme ovisno o zatečenim odstupanjima na konkretnom mjestu ugradnje. Prije početka izrade takve baze znanja potrebno je postaviti sustav relevantnih varijabli koje utječu na konačni rezultat te ih na pogodan način sistematizirati. Neke od njih su npr. promjer cjevovoda, duljina cijevi, debljina stijenke, materijal cijevi,

ly by applying the finite element method and a right decision can be easily taken whether the measured deviation is acceptable or not. The results obtained by the analysis of the presented example have shown that very small deviations could cause too high stresses in the pump housing if the pump is mounted irregularly.

The analysis performed in this paper opens additional questions that the authors intend to research too. The final aim of such a research is the formation of a basis of knowledge with all data concerning the possibility of mounting pumps and other equipment depending on the measured deviations at a particular place of installation included. But before forming a basis of knowledge, it is necessary to set up a system of relevant variables which have an influence on the final result and to systemize them in a

tip oslonca, udaljenost oslonca od prirubnice, izvedba i veličina pumpi i sl. Ovdje treba napomenuti da bi se takva analiza trebala izraditi u suradnji s proizvodnim subjektom (npr. brodogradilištem) te bi se prilagodila specifičnom pristupu u gradnji cjevovoda. Korist od tako izrađene baze znanja je neupitna, jer umanjuje troškove pri gradnji broda i preventivno umanjuje mogućnost kvarova i oštećenja opreme u eksploataciji.

6. ZAHVALA

Modeli cjevovoda, analize i proračuni u ovom radu izrađeni su na temelju tehničke dokumentacije koju je autorima pružio na raspolaganje Ured za izradu radioničke dokumentacije brodogradilišta „3. maj”. Posebnu zahvalu autoru upućuju Rajku Rubeši, dipl. ing. na susretljivosti i pomoći pri pribavljanju potrebnih podataka za provedbu analize opisane u ovom radu.

suitable way. Some of them are as follows: pipe diameter, pipe length, pipe wall thickness, pipe material, support type, distance between the support and the flange, type and size of the pump etc. It must also be pointed out that such an analysis should be carried out in collaboration with the production entity (e. g. shipyard) and should be adapted to a specific approach in the piping production. The benefit of a basis of knowledge so formed is beyond any dispute, because it lowers the cost of the shipbuilding and decreases the possibility of the equipment failure or damage during exploitation.

6 ACKNOWLEDGEMENT

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