

## Математическое моделирование подъема жатки

### 1 Исходные данные:

Координаты звеньев в правой системе координат

$$\begin{array}{lll} X01 := 0.196 & X03 := 0.049 & X05 := 0.283 \\ Y01 := 0.693 & Y03 := 1.327 & Y05 := 0.521 \end{array}$$

Изменение обобщенной координаты (ход гидроцилиндра)

$$S := 0.650, 0.660 \dots 0.800$$

Длины звеньев механизма подъема

Вес и координаты центра тяжести жатки

$$\begin{array}{llll} L3 := 0.17194 & L4 := 0.657 & P := 1500 & XN := 1.259 \\ L34 := 0.4804 & L5 := 0.513 & & YN := 0.482 \\ & L6 := 0.938 & & \end{array}$$

Предполагаемые диаметры поршней гидроцилиндра

$$D := 0.080 \quad D1 := 0.063 \quad D2 := 0.050$$

Максимальное давление гидроцилиндра [Па]

$$p := 15 \cdot 10^6$$

Механический и гидравлический КПД

$$\eta_m := 0.85 \quad \eta_h := 0.96$$

Преобразование радиан в градусы и наоборот

$$rg := \frac{180}{\pi} \quad gr := \frac{1}{rg}$$

### 2. Анализ механизма подъема

#### 2.1. Определение максимального усилия раздвигаемого гидроцилиндром

$$\begin{array}{ll} SS := \pi \cdot D^2 \cdot 0.25 & SS1 := \pi \cdot D1^2 \cdot 0.25 \\ SS = 5.02655 \times 10^{-3} & \\ F_{max} := \frac{p \cdot SS \cdot kg}{9.81} & F_{max1} := \frac{p \cdot SS1 \cdot kg}{9.81} \end{array}$$

$$F_{max} = 7.378 \times 10^3 \quad F_{max1} = 4.576 \times 10^3$$

$$\begin{array}{ll} SS2 := \pi \cdot D2^2 \cdot 0.25 & \\ F_{max2} := \frac{p \cdot SS2 \cdot kg}{9.81} \end{array}$$

$$F_{max2} = 2.882 \times 10^3$$

## 2.2. Геометрический анализ механизма набежки

$$L0 := \sqrt{(X01 - X03)^2 + (Y01 - Y03)^2}$$

$$L0 = 0.651$$

$$L2 := \sqrt{(X03 - X05)^2 + (Y03 - Y05)^2}$$

$$L2 = 0.839$$

$$T1 := \operatorname{atan}\left(\frac{X01 - X03}{Y03 - Y01}\right)$$

$$T1 \cdot \operatorname{rg} = 13.054$$

$$T2 := \frac{\pi}{2} - \operatorname{atan}\left(\frac{X05 - X03}{Y03 - Y05}\right)$$

$$T2 \cdot \operatorname{rg} = 73.811$$

$$FI3(S) := \operatorname{asin}\left[\frac{S^2 - (L3^2 + L0^2)}{2 \cdot L3 \cdot L0}\right] + T1$$

$$\operatorname{DELFI} := \operatorname{acos}\left(\frac{L3^2 + L4^2 - L34^2}{2 \cdot L3 \cdot L4}\right)$$

$$\operatorname{DELFI} \cdot \operatorname{rg} = 11.415i$$

$$FI4(S) := FI3(S) - \operatorname{DELFI}$$

$$FI42(S) := FI4(S) + T2$$

$$FI(S) := \operatorname{atan}\left(\frac{-L4 \cdot \sin(FI42(S))}{L2 - L4 \cdot \cos(FI42(S))}\right)$$

$$\overset{\text{www}}{L}(S) := -L4 \cdot \frac{\sin(FI42(S))}{\sin(FI(S))}$$

$$L1(S) := \sqrt{L4^2 + L2^2 - 2 \cdot L4 \cdot L2 \cdot \cos(FI42(S))}$$

Табл. 1 Зависимость промежуточных и выходных параметров от обобщенной координаты

$S =$				
0.65				
0.66		5.188		$5.188 - 11.415i$
0.67		8.562		$8.562 - 11.415i$
0.68		11.971		$11.971 - 11.415i$
0.69		15.428		$15.428 - 11.415i$
0.7		18.945		$18.945 - 11.415i$
0.71		22.537		$22.537 - 11.415i$
0.72		26.219		$26.219 - 11.415i$
0.73	$FI3(S) \cdot rg =$	30.011	$FI4(S) \cdot rg =$	$30.011 - 11.415i$
0.74		33.935		$33.935 - 11.415i$
0.75		38.022		$38.022 - 11.415i$
0.76		42.309		$42.309 - 11.415i$
0.77		46.845		$46.845 - 11.415i$
0.78		51.702		$51.702 - 11.415i$
0.79		56.985		$56.985 - 11.415i$
0.8		62.866		$62.866 - 11.415i$
		69.668		$69.668 - 11.415i$
	$FI42(S) \cdot rg =$	$FI(S) \cdot rg =$	$L(S) =$	$L1(S) =$
	$78.999 - 11.415i$	$-42.286 - 4.053i$	$0.966 - 0.112i$	$0.966 - 0.112i$
	$82.373 - 11.415i$	$-41.058 - 4.158i$	$0.999 - 0$	$0.999 - 0$
	$85.782 - 11.415i$	$-39.789 - 4.252i$	$1.032 - 0$	$1.032 - 0$
	$89.239 - 11.415i$	$-38.477 - 4.337i$	$1.064 - 0$	$1.064 - 0$
	$92.756 - 11.415i$	$-37.119 - 4.414i$	$1.096 - 0$	$1.096 - 0$
	$96.348 - 11.415i$	$-35.71 - 4.483i$	$1.127 - 0$	$1.127 - 0$
	$100.03 - 11.415i$	$-34.246 - 4.547i$	$1.158 - 0$	$1.158 - 0$
	$103.821 - 11.415i$	$-32.719 - 4.605i$	$1.189 - 0$	$1.189 - 0$
	$107.746 - 11.415i$	$-31.12 - 4.659i$	$1.219 - 0$	$1.219 - 0$
	$111.833 - 11.415i$	$-29.437 - 4.708i$	$1.249 - 0$	$1.249 - 0$
	$116.12 - 11.415i$	$-27.655 - 4.754i$	$1.28 - 0$	$1.28 - 0$
	$120.656 - 11.415i$	$-25.752 - 4.797i$	$1.31 - 0$	$1.31 - 0$
	$125.512 - 11.415i$	$-23.698 - 4.837i$	$1.339 - 0$	$1.339 - 0$
	$130.795 - 11.415i$	$-21.447 - 4.874i$	$1.369 - 0$	$1.369 - 0$
	$136.677 - 11.415i$	$-18.922 - 4.908i$	$1.399 - 0$	$1.399 - 0$
	$143.479 - 11.415i$	$-15.984 - 4.941i$	$1.429 - 0$	$1.429 - 0$

$$FI5S(S) := \arccos\left(\frac{L6^2 - L(S)^2 - L5^2}{2 \cdot L5 \cdot L(S)}\right)$$

$$FI52(S) := FI(S) + FI5S(S)$$

$$FI5(S) := FI52(S) - T2$$

$$FI6S(S) := \arccos\left(\frac{L6^2 + L(S)^2 - L5^2}{2 \cdot L6 \cdot L(S)}\right) + \pi$$

$$FI62(S) := FI(S) + FI6S(S)$$

$$FI6(S) := FI62(S) - T2$$

Табл. 2. Зависимость промежуточных и выходных параметров от обобщенной координаты

S =					
0.65					
0.66		108.814 -	211.778 -	-7.283 - 1°	95.681 -
0.67		111.928 -	211.031 +	-2.941 - 1°	96.162 -
0.68		114.996 -	210.207 +	1.397 - 14	96.608 -
0.69		118.039 -	209.31 +	5.751 - 1°	97.022 -
0.7		121.073 -	208.338 +	10.143 - 1°	97.409 -
0.71		124.117 -	207.29 +	14.596 - 1°	97.769
0.72		127.19 -	206.163 +	19.134 - 1°	98.106 -
0.73	FI5S(S)·rg =	130.314 -	204.95 -	23.785 - 1°	98.42 -
0.74		133.513 -	203.642 +	28.582 - 1°	98.711 -
0.75		136.817 -	202.227 +	33.569 - 1°	98.979 -
0.76		140.264 -	200.687 +	38.798 - 1°	99.222 -
0.77		143.906 -	198.997 +	44.343 - 1°	99.434 -
0.78		147.816	197.116 +	50.307 - 1°	99.607 -
0.79		152.106 -	194.986 +	56.848 - 1°	99.728 -
0.8		156.956 -	192.505 +	64.223 - 1°	99.772 -
		162.647 -	189.517 +	72.853 - 1°	99.722 -

### 2.3. Проверка геометрического анализа механизма подъема

$$X46(S) := X03 + L4 \cdot \cos(FI4(S))$$

$$Y46(S) := Y03 + L4 \cdot \sin(FI4(S))$$

$$X56(S) := X05 + L5 \cdot \cos(FI5(S))$$

$$Y56(S) := Y05 + L5 \cdot \sin(FI5(S))$$

$$X461(S) := X56(S) + L6 \cdot \cos(FI6(S))$$

$$Y461(S) := Y56(S) + L6 \cdot \sin(FI6(S))$$

Табл. 3. Зависимость выходных координат МП от обобщенной координаты

$S =$	$X_{46}(S) =$	$X_{461}(S) =$	$Y_{46}(S) =$
0.65	$0.716 + 0.012i$	$0.716 + 0.012i$	$1.388 - 0.131i$
0.66	$0.712 + 0.02i$	$0.712 + 0.02i$	$1.427 - 0.13i$
0.67	$0.705 + 0.027i$	$0.705 + 0.027i$	$1.466 - 0.129i$
0.68	$0.695 + 0.035i$	$0.695 + 0.035i$	$1.505 - 0.127i$
0.69	$0.683 + 0.043i$	$0.683 + 0.043i$	$1.545 - 0.125i$
0.7	$0.668 + 0.051i$	$0.668 + 0.051i$	$1.584 - 0.122i$
0.71	$0.65 + 0.058i$	$0.65 + 0.058i$	$1.623 - 0.118i$
0.72	$0.629 + 0.066i$	$0.629 + 0.066i$	$1.662 - 0.114i$
0.73	$0.605 + 0.074i$	$0.605 + 0.074i$	$1.701 - 0.109i$
0.74	$0.577 + 0.081i$	$0.577 + 0.081i$	$1.74 - 0.104i$
0.75	$0.545 + 0.089i$	$0.545 + 0.089i$	$1.778 - 0.097i$
0.76	$0.507 + 0.096i$	$0.507 + 0.096i$	$1.816 - 0.09i$
0.77	$0.464 + 0.103i$	$0.464 + 0.103i$	$1.853 - 0.082i$
0.78	$0.414 + 0.11i$	$0.414 + 0.11i$	$1.889 - 0.072i$
0.79	$0.355 + 0.117i$	$0.355 + 0.117i$	$1.923 - 0.06i$
0.8	$0.282 + 0.124i$	$0.282 + 0.124i$	$1.955 - 0.046i$

$Y_{461}(S) =$	$\begin{pmatrix} 1.388 - 0.131i \\ 1.427 - 0.13i \\ 1.466 - 0.129i \\ 1.505 - 0.127i \\ 1.545 - 0.125i \\ 1.584 - 0.122i \\ 1.623 - 0.118i \\ 1.662 - 0.114i \\ 1.701 - 0.109i \\ 1.74 - 0.104i \\ 1.778 - 0.097i \\ 1.816 - 0.09i \\ 1.853 - 0.082i \\ 1.889 - 0.072i \\ 1.923 - 0.06i \\ 1.955 - 0.046i \end{pmatrix}$	$X_{56}(S) =$	$\begin{pmatrix} 0.809 - 0.017i \\ 0.812 - 6.841i \times 10^{-3} \\ 0.812 + 3.211i \times 10^{-3} \\ 0.81 + 0.013i \\ 0.804 + 0.023i \\ 0.795 + 0.032i \\ 0.782 + 0.042i \\ 0.767 + 0.051i \\ 0.747 + 0.061i \\ 0.723 + 0.07i \\ 0.695 + 0.08i \\ 0.661 + 0.089i \\ 0.621 + 0.099i \\ 0.573 + 0.11i \\ 0.514 + 0.123i \\ 0.44 + 0.14i \end{pmatrix}$	$S =$	$\begin{pmatrix} 0.454 - 0.134i \\ 0.494 - 0.133i \\ 0.534 - 0.132i \\ 0.574 - 0.13i \\ 0.614 - 0.127i \\ 0.654 - 0.124i \\ 0.694 - 0.121i \\ 0.734 - 0.116i \\ 0.774 - 0.111i \\ 0.813 - 0.106i \\ 0.852 - 0.099i \\ 0.89 - 0.091i \\ 0.928 - 0.082i \\ 0.964 - 0.072i \\ 0.999 - 0.059i \\ 1.031 - 0.043i \end{pmatrix}$
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$$X := XN - 0.767 \quad Y := YN - 0.355 \quad \text{atan}\left(\frac{Y}{X}\right) \cdot \text{rg} = 14.474$$

$$LS6 := \sqrt{X^2 + Y^2} \quad FIS6 := 2 \cdot \pi + \text{atan}\left(\frac{Y}{X}\right) - FI6(0.650)$$

$$LS6 = 0.508 \quad FIS6 = 4.866 + 0.031i \quad FIS6 := 4.894 \quad FIS6 \cdot \text{rg} = 280.406$$

## 2.4. Кинематический анализ МП

### 2.4.1. Определение аналога угловой скорости поворотного рычага

$$DFI3(S) := \frac{2 \cdot S}{\sqrt{4 \cdot L0^2 \cdot L3^2 - [S^2 - (L3^2 + L0^2)]^2}}$$

### 2.4.2. Определение аналогов угловой скорости звеньев МП

$$U54(S) := \frac{L4 \cdot \sin(FI4(S) - FI6(S))}{L5 \cdot \sin(FI5(S) - FI6(S))}$$

$$U65(S) := \frac{L5 \cdot \sin(FI5(S) - FI4(S))}{L6 \cdot \sin(FI4(S) - FI6(S))}$$

### 2.5. Определение передаточного числа МП и нагрузки на гидроцилиндры

$$Im(S) := DFI3(S) \cdot U54(S) \cdot L5 \cdot \cos(FI5(S))$$

$$dell(S) := DFI3(S) \cdot U65(S) \cdot LS6 \cdot \cos(FI6(S) + FIS6)$$

$$Is(S) := Im(S) + dell(S) \quad FS(S) := \frac{P \cdot Is(S)}{km}$$

Табл. 4. Зависимость передаточного числа МП и нагрузки на гидроцилиндры (2) от обобщенной координаты

$S =$		$DFI3(S) =$	$U65(S) =$	
0.65		5.864	$0.117 + 0.033i$	
0.66		5.916	$0.108 + 0.03i$	
0.67		5.988	$0.1 + 0.028i$	
0.68		6.082	$0.092 + 0.026i$	
0.69		6.199	$0.085 + 0.024i$	
0.7		6.342	$0.078 + 0.023i$	
0.71		6.516	$0.071 + 0.022i$	
0.72		6.727	$0.064 + 0.022i$	
0.73		6.982	$0.057 + 0.022i$	
0.74		7.295	$0.05 + 0.023i$	
0.75		7.682	$0.042 + 0.024i$	
0.76		8.172	$0.033 + 0.027i$	
0.77		8.811	$0.023 + 0.032i$	
0.78		9.679	$0.011 + 0.041i$	
0.79		10.94	$-5.608 \times 10^{-3} + 0.0$	
0.8		12.992	$-0.024 + 0.096i$	
				$7.652 \times 10^3 + 2$
				$7.621 \times 10^3 + 3$
				$7.592 \times 10^3 + 4$
				$7.562 \times 10^3 + 5$
				$7.528 \times 10^3 + 6$
				$7.49 \times 10^3 + 7$
				$7.444 \times 10^3 + 8$
				$7.387 \times 10^3 + 9$
				$7.316 \times 10^3 + 1.0$
				$7.223 \times 10^3 + 1.2$
				$7.101 \times 10^3 + 1.4$
				$6.935 \times 10^3 + 1.6$
				$6.703 \times 10^3 + 1.9$
				$6.364 \times 10^3 + 2.3$
				$5.84 \times 10^3 + 3.0$
				$4.998 \times 10^3 + 4.3$
$Im(S) =$	$dell(S) =$		$Is(S) =$	$S(S) =$
$4.003 + 0.077i$	$0.333 + 0.096i$		$4.336 + 0.168i$	
$4.008 + 0.11i$	$0.31 + 0.089i$		$4.319 + 0.21i$	
$4.012 + 0.11i$	$0.29 + 0.083i$		$4.302 + 0.254i$	
$4.013 + 0.21i$	$0.272 + 0.078i$		$4.285 + 0.301i$	
$4.012 + 0.21i$	$0.255 + 0.074i$		$4.266 + 0.351i$	
$4.006 + 0.31i$	$0.239 + 0.072i$		$4.244 + 0.406i$	
$3.995 + 0.31i$	$0.223 + 0.071i$		$4.218 + 0.466i$	
$3.978 + 0.41i$	$0.208 + 0.072i$		$4.186 + 0.533i$	
$3.954 + 0.51i$	$0.192 + 0.074i$		$4.146 + 0.609i$	
$3.918 + 0.61i$	$0.175 + 0.08i$		$4.093 + 0.696i$	
$3.869 + 0.71i$	$0.155 + 0.089i$		$4.024 + 0.801i$	
$3.8 + 0.82i$	$0.13 + 0.106i$		$3.93 + 0.929i$	
$3.701 + 0.91i$	$0.097 + 0.134i$		$3.799 + 1.097i$	
$3.558 + 1.11i$	$0.048 + 0.188i$		$3.607 + 1.334i$	
$3.338 + 1.41i$	$-0.029 + 0.301i$		$3.309 + 1.712i$	
$2.978 + 1.81i$	$-0.146 + 0.596i$		$2.832 + 2.46i$	

Табл. 5. Доля использования максимального усилия развиваемого различными гидроцилиндрами по отношению к данной нагрузке

$S = \begin{pmatrix} 0.65 \\ 0.66 \\ 0.67 \\ 0.68 \\ 0.69 \\ 0.7 \\ 0.71 \\ 0.72 \\ 0.73 \\ 0.74 \\ 0.75 \\ 0.76 \\ 0.77 \\ 0.78 \\ 0.79 \\ 0.8 \end{pmatrix}$	$\frac{FS(S)}{2 \cdot F_{max}} =$	$\begin{pmatrix} 0.519 + 0.02i \\ 0.516 + 0.025i \\ 0.514 + 0.03i \\ 0.512 + 0.036i \\ 0.51 + 0.042i \\ 0.508 + 0.049i \\ 0.504 + 0.056i \\ 0.501 + 0.064i \\ 0.496 + 0.073i \\ 0.489 + 0.083i \\ 0.481 + 0.096i \\ 0.47 + 0.111i \\ 0.454 + 0.131i \\ 0.431 + 0.159i \\ 0.396 + 0.205i \\ 0.339 + 0.294i \end{pmatrix}$	$\frac{FS(S)}{2 \cdot F_{max1}} =$	$\begin{pmatrix} 0.836 + 0 \\ 0.833 + 0 \\ 0.83 + 0 \\ 0.826 + 0 \\ 0.823 + 0 \\ 0.818 + 0 \\ 0.813 + 0 \\ 0.807 + 0 \\ 0.799 + 0 \\ 0.789 + 0 \\ 0.776 + 0 \\ 0.758 + 0 \\ 0.732 + 0 \\ 0.695 + 0 \\ 0.638 + 0 \\ 0.546 + 0 \end{pmatrix}$	$\frac{FS(S)}{2 \cdot F_{max2}} =$	$\begin{pmatrix} 1.327 + 0.051 \\ 1.322 + 0.064 \\ 1.317 + 0.078 \\ 1.312 + 0.092 \\ 1.306 + 0.107 \\ 1.299 + 0.124 \\ 1.291 + 0.143 \\ 1.282 + 0.163 \\ 1.269 + 0.186 \\ 1.253 + 0.213 \\ 1.232 + 0.245 \\ 1.203 + 0.284 \\ 1.163 + 0.336 \\ 1.104 + 0.408 \\ 1.013 + 0.524 \\ 0.867 + 0.753 \end{pmatrix}$
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Диаграмма 1. Зависимость основного коэф. кинематической передачи от обобщенной координаты

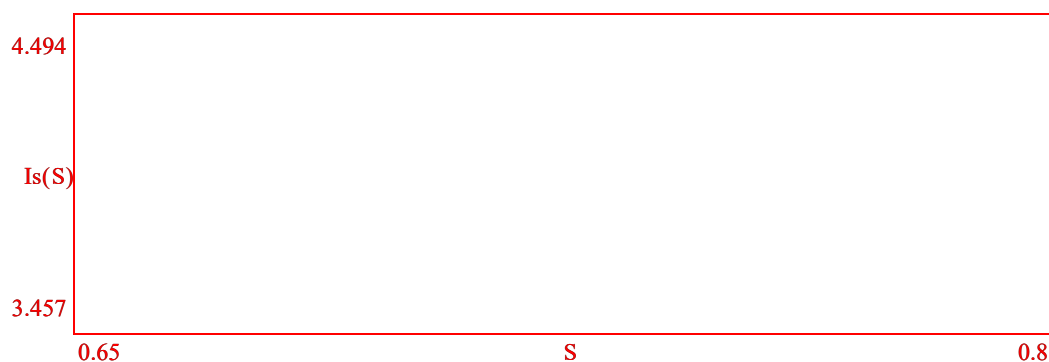
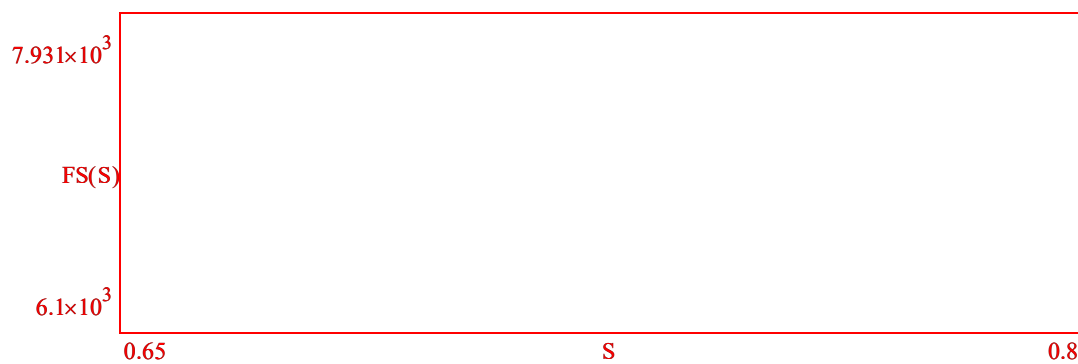
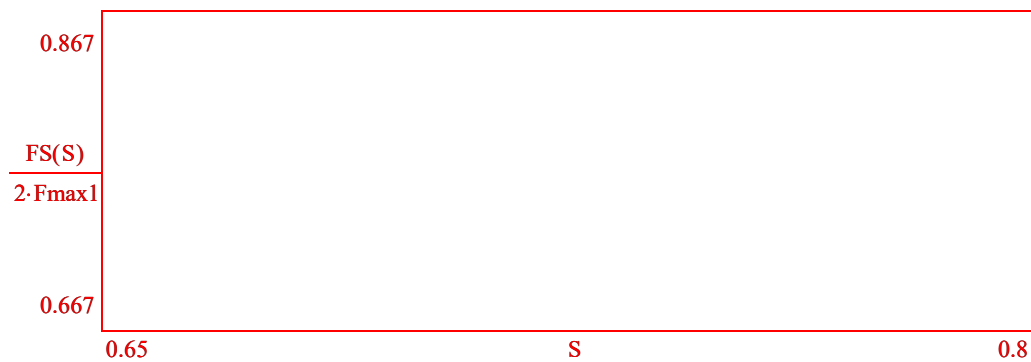
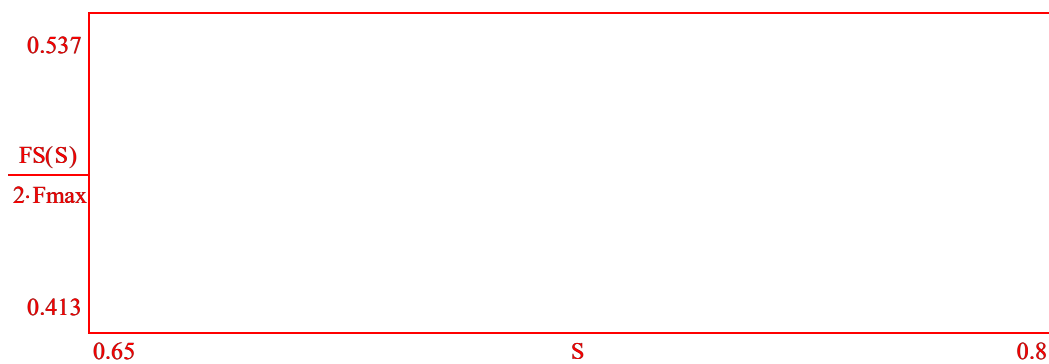


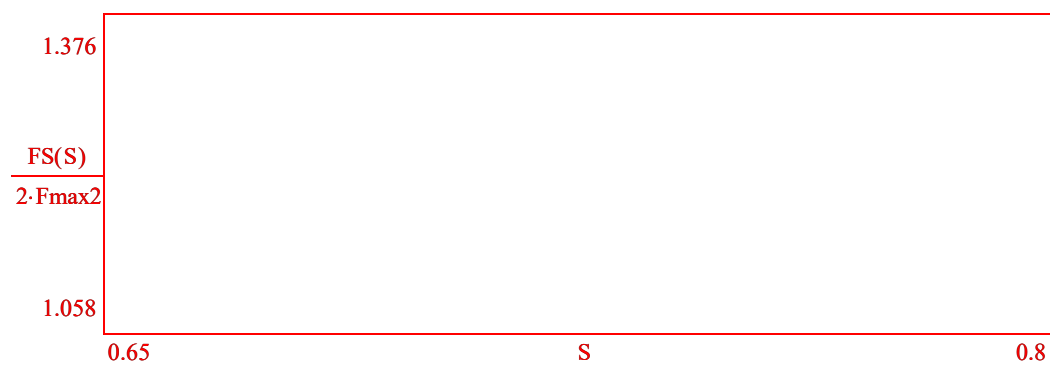


Диаграмма 2. Зависимость нагрузки на гидроцилиндры от обобщенной координаты



Диаграммы поясняющие долю максимального усилия используемую различными гидроцилиндрами в зависимости от определенной нагрузки







12i )  
1i  
07i  
04i  
01i  
98i  
94i  
9i  
86i  
82i  
'8i  
'3i  
57i  
51i  
54i  
46i )

- 1.783i  
- 1.625i  
- 1.483i  
- 1.353i  
- 1.233i  
- 1.12i  
- 1.011i  
- 0.905i  
- 0.798i  
- 0.687i  
- 0.567i  
- 0.429i  
- 0.258i  
- 0.028i  
+ 0.328i  
+ 0.989i

1

$$\left. \begin{array}{l} .95.846i \\ .69.784i \\ .47.626i \\ .30.415i \\ .19.351i \\ 15.902i \\ 321.96i \\ 40.079i \\ 74i \times 10^3 \\ 29i \times 10^3 \\ 13i \times 10^3 \\ 54i \times 10^3 \\ 36i \times 10^3 \\ 53i \times 10^3 \\ 22i \times 10^3 \\ 41i \times 10^3 \end{array} \right\}$$

[illegible]

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