1

On a conjecture by A. Durfee

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Abstract

We show how *superisolated surface singularities* can be used to find a counterexample to the following conjecture by A. Durfee [8]: for a complex polynomial $f(x, y, z)$ in three variables vanishing at 0 with an isolated singularity there, "the local complex algebraic monodromy is of finite order if and only if a resolution of the germ $(\{f = 0\}, 0)$ has no cycles". A Zariski pair is given whose corresponding superisolated surface singularities, one has complex algebraic monodromy of finite order and the other not (answering a question by J. Stevens).

1. Introduction

In this paper we give an example of a *superisolated surface singularity* $(V, 0) \subset (\mathbb{C}^3, 0)$ such that a resolution of the germ $(V, 0)$ has no cycles and the local complex algebraic monodromy of the germ $(V, 0)$ is not of finite order, contradicting a conjecture proposed by Durfee [8].

For completeness in the second section we recall well known results about monodromy of the Milnor fibration, about normal surface singularities and state the question by Durfee.

In the third section we recall results on superisolated surface singularities and with them we study in detail the counterexample.

In the last section we show a Zariski pair (C_1, C_2) of curves of degree d given by homogeneous polynomials $f_1(x, y, z)$ and $f_2(x, y, z)$ whose

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corresponding superisolated surface singularities $(V_1, 0) = (\{f_1(x, y, z) + l^{d+1} = 0\}, 0) \subset (\mathbb{C}^3, 0)$ and $(V_2, 0) = (\{f_2(x, y, z) + l^{d+1} = 0\}, 0) \subset (\mathbb{C}^3, 0)$ (l is a generic hyperplane) satisfy: 1) $(V_1, 0)$ has complex algebraic monodromy of finite order and 2) $(V_2, 0)$ has complex algebraic monodromy of infinite order (answering a question proposed to us by J. Stevens).

2. Invariants of singularities

2.1. Monodromy of the Milnor fibration

Let $f : (\mathbb{C}^{n+1}, 0) \to (\mathbb{C}, 0)$ be an analytic function defining a germ $(V, 0) := (f^{-1}\{0\}, 0) \subset (\mathbb{C}^{n+1}, 0)$ of a hypersurface singularity. The *Milnor fibration* of the holomorphic function f at 0 is the C^∞ locally trivial fibration $f| : B_\varepsilon(0) \cap f^{-1}(\mathbb{D}^*_\eta) \to \mathbb{D}^*_\eta$, where $B_\varepsilon(0)$ is the open ball of radius ε centered at 0, $\mathbb{D}_\eta = \{z \in \mathbb{C} : |z| < \eta\}$ and $\mathbb{D}^*_\eta$ is the open punctured disk ($0 < \eta \ll \varepsilon$ and ε small enough). Milnor's classical result also shows that the topology of the germ $(V, 0)$ in $(\mathbb{C}^{n+1}, 0)$ is determined by the pair $(S^{2n+1}_\varepsilon, L^{2n-1}_V)$, where $S^{2n+1} = \partial B_\varepsilon(0)$ and $L^{2n-1}_V := S^{2n+1}_\varepsilon \cap V$ is the *link* of the singularity.

Any fiber $F_{f,0}$ of the Milnor fibration is called the *Milnor fiber* of f at 0. The *monodromy transformation* $h : F_{f,0} \to F_{f,0}$ is the well-defined (up to isotopy) diffeomorphism of $F_{f,0}$ induced by a small loop around $0 \in \mathbb{D}_\eta$. The *complex algebraic monodromy of* f *at* 0 is the corresponding linear transformation $h_* : H_*(F_{f,0}, \mathbb{C}) \to H_*(F_{f,0}, \mathbb{C})$ on the homology groups.

If $(V, 0)$ defines a germ of isolated hypersurface singularity then $\tilde{H}_j(F_{f,0}, \mathbb{C}) = 0$ but for $j = 0, n$. In particular the non-trivial complex algebraic monodromy will be denoted by $h : H_n(F_{f,0}, \mathbb{C}) \to H_n(F_{f,0}, \mathbb{C})$ and $\Delta_V(t)$ will denote its characteristic polynomial.

2.2. Monodromy Theorem and its supplements

The following are the **main properties of the monodromy operator**, see e.g. [11]:

(a) $\Delta_V(t)$ is a product of cyclotomic polynomials.
(b) Let N be the maximal size of the Jordan blocks of h, then $N \leq n + 1$.
(c) Let N_1 be the maximal size of the Jordan blocks of h for the eigenvalue 1, then $N_1 \leq n$.
(d) The monodromy h is called of *finite order* if there exists $N > 0$ such that $h^N = Id$. Lê D.T. [12] proved that the monodromy of an irreducible plane curve singularity is of finite order.
(e) This result was extended by van Doorn and Steenbrink [7] who showed that if h has a Jordan block of maximal size $n + 1$ then

$N_1 = n$, i.e. there exists a Jordan block of h of maximal size n for the eigenvalue 1.

Milnor proved that the link L_V^{2n-1} is $(n-2)$-connected. Thus the link is an *integer (resp. rational) homology* $(2n-1)$*-sphere* if $H_{n-1}(L_V^{2n-1}, \mathbb{Z}) = 0$ (resp. $H_{n-1}(L_V^{2n-1}, \mathbb{Q}) = 0$). These can be characterized considering the natural map $h - id : H_n(F_{f,0}, \mathbb{Z}) \to H_n(F_{f,0}, \mathbb{Z})$ and using Wang's exact sequence which reads as (see e.g. [19, 21]):

$$0 \to H_n\big(L_V^{2n-1}, \mathbb{Z}\big) \to H_n(F_{f,0}, \mathbb{Z}) \to H_n(F_{f,0}, \mathbb{Z}) \to H_{n-1}\big(L_V^{2n-1}, \mathbb{Z}\big) \to 0.$$

Thus rank $H_n(L_V^{2n-1}) = \text{rank } H_{n-1}(L_V^{2n-1}) = \dim\ker(h - id)$ and:

- L_V^{2n-1} is a rational homology $(2n-1)$-sphere $\iff \Delta_V(1) \neq 0$,
- L_V^{2n-1} is an integer homology $(2n-1)$-sphere $\iff \Delta_V(1) = \pm 1$.

2.3. Normal surface singularities

Let $(V, 0) = (\{f_1 = \ldots = f_m = 0\}, 0) \subset (\mathbb{C}^N, 0)$ be a normal surface singularity with link $L_V := V \cap S_\varepsilon^{2N-1}$, L_V is a a connected compact oriented 3-manifold. Since $V \cap B_\varepsilon$ is a cone over the link L_V then L_V characterizes the topological type of $(V, 0)$. The link L_V is called a *rational homology sphere* ($\mathbb{Q}$HS) if $H_1(L_V, \mathbb{Q}) = 0$, and L_V is called an *integer homology sphere* ($\mathbb{Z}$HS) if $H_1(L_V, \mathbb{Z}) = 0$. One of the main problems in the study of normal surfaces is to determine which analytical properties of $(V, 0)$ can be read from the topology of the singularity, see the very nice survey paper by Nemethi [20].

The resolution graph $\Gamma(\pi)$ of a resolution $\pi : \tilde{V} \to V$ allows to relate analytical and topological properties of V. W. Neumann [22] proved that the information carried in any resolution graph is the same as the information carried by the link L_V. Let $\pi : \tilde{V} \to V$ be a *good* resolution of the singular point $0 \in V$. Good means that $E = \pi^{-1}\{0\}$ is a normal crossing divisor. Let $\Gamma(\pi)$ be the dual graph of the resolution (each vertex decorated with the genus $g(E_i)$ and the self-intersection E_i^2 of E_i in $\tilde{V}$). Mumford proved that the intersection matrix $I = (E_i \cdot E_j)$ is negative definite and Grauert proved the converse, i.e., any such graph comes from the resolution of a normal surface singularity.

Considering the exact sequence of the pair $(\tilde{V}, E)$ and using I is non-degenerated then

$$0 \longrightarrow \text{coker } I \longrightarrow H_1(L_V, \mathbb{Z}) \longrightarrow H_1(E, \mathbb{Z}) \longrightarrow 0$$

and rank $H_1(E) = \text{rank } H_1(L_V)$. In fact L_V is a $\mathbb{Q}$HS if and only if $\Gamma(\pi)$ is a tree and every E_i is a rational curve. If additionally I has determinant ± 1 then L_V is an $\mathbb{Z}$HS.

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2.4. Number of cycles in the exceptional set E and Durfee's conjecture

In general one gets

$$\operatorname{rank} H_1(L_V) = \operatorname{rank} H_1(\Gamma(\pi)) + 2\sum_i g(E_i),$$

where rank $H_1(\Gamma(\pi))$ is the number of independent cycles of the graph $\Gamma(\pi)$. Let $n : \tilde{E} \to E$ be the normalization of E. Durfee showed in [8] that the *number of cycles* $c(E)$ *in* E, i.e. $c(E) = \operatorname{rank} H_1(E) - \operatorname{rank} H_1(\tilde{E})$, does not depend on the resolution and in fact it is equal to $c(E) = \operatorname{rank} H_1(\Gamma(\pi))$. Therefore, E contains cycles only when the dual graph of the intersections of the components contains a cycle. Durfee in [8] proposed the following

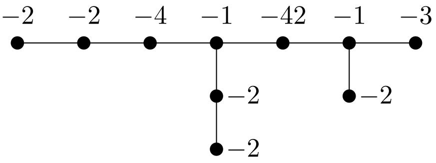
Conjecture. *For a complex polynomial $f(x, y, z)$ in three variables vanishing at* 0 *with an isolated singularity there, "the local complex algebraic monodromy h is of finite order if and only if a resolution of the germ* $(\{f = 0\}, 0)$ *has no cycles".*

He showed that the conjecture is true in the following two cases:

(1) if f is weighted homogeneuos (the resolution graph is star-shaped and therefore its monodromy is finite)
(2) if $f = g(x, y) + z^n$. Using Thom-Sebastiani [27], the monodromy of f is finite if and only if the monodromy of g is finite. Theorem 3 in [8] proves that the monodromy of f is of finite order if and only a resolution of f has no cycles.

2.5. Example (main result)

In this paper we show that the conjecture is not true in general, and for that we use superisolated surface singularities. Let $(V, 0) \subset (\mathbb{C}^3, 0)$ be the germ of normal surface singularity defined by $f := (xz - y^2)^3 - ((y - x)x^2)^2 + z^7 = 0$. Then the minimal good resolution graph Γ_V of (the superisolated singularity) $(V, 0)$ is

Γ_V:


where every dot denotes a rational non-singular curve with the corresponding self-intersection. Thus the link L_V is a rational homology sphere and in particular this graph is a tree, i.e. it has no cycles. But the complex algebraic monodromy of f at 0 does not have finite order because there exists a Jordan block of size 2×2 for an eigenvalue $\neq 1$.

3. Superisolated surface singularities

Definition 3.1. A hypersurface surface singularity $(V, 0) \subset (\mathbb{C}^3, 0)$ defined as the zero locus of $f = f_d + f_{d+1} + \cdots \in \mathbb{C}\{x, y, z\}$ (where f_j is homogeneous of degree j) is *superisolated*, SIS for short, if the singular points of the complex projective plane curve $C := \{f_d = 0\} \subset \mathbb{P}^2$ are not situated on the projective curve $\{f_{d+1} = 0\}$, that is $\mathrm{Sing}(C) \cap \{f_{d+1} = 0\} = \emptyset$. Note that C must be reduced.

The SIS were introduced by I. Luengo in [17] to study the μ-constant stratum. The main idea is that for a SIS the embedded topological type (and the equisingular type) of $(V, 0)$ does not depend on the choice of f_j's (for $j > d$, as long as f_{d+1} satisfies the above requirement), e.g. one can take $f_j = 0$ for any $j > d + 1$ and $f_{d+1} = l^{d+1}$ where l is a linear form not vanishing at the singular points [18].

3.1. The minimal resolution of a SIS

Let $\pi : \tilde{V} \to V$ be the monoidal transformation centered at the maximal ideal $\mathfrak{m} \subset \mathcal{O}_V$ of the local ring of V at 0. Then $(V, 0)$ is a SIS if and only if $\tilde{V}$ is a non-singular surface. Thus π is the *minimal resolution* of $(V, 0)$. To construct the resolution graph $\Gamma(\pi)$ consider $C = C_1 + \cdots + C_r$ the decomposition in irreducible components of the reduced curve C in $\mathbb{P}^2$. Let d_i (resp. g_i) be the degree (resp. genus) of the curve C_i in $\mathbb{P}^2$. Then $\pi^{-1}\{0\} \cong C = C_1 + \cdots + C_r$ and the self-intersection of C_i in $\tilde{V}$ is $C_i \cdot C_i = -d_i(d - d_i + 1)$, [17, Lemma 3]. Since the link L_V can be identified with the boundary of a regular neighbourhood of $\pi^{-1}\{0\}$ in $\tilde{V}$ then the topology of the tangent cone determines the topology of the abstract link L_V [17].

3.2. The minimal good resolution of a SIS

The minimal good resolution of a SIS $(V, 0)$ is obtained after π by doing the minimal embedded resolution of each plane curve singularity $(C, P) \subset (\mathbb{P}^2, P)$, $P \in \mathrm{Sing}(C)$. This means that the support of the minimal good resolution graph

Γ_V is the same as the minimal embedded resolution graph Γ_C of the projective plane curve C in $\mathbb{P}^2$. The decorations of the minimal good resolution graph Γ_V are as follows:

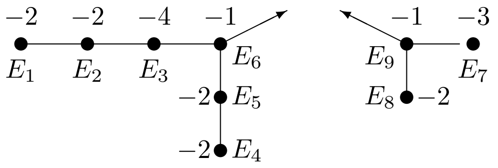
1) the genus of (the strict transform of) each irreducible component C_i of C is a birational invariant and then one can compute it as an embedded curve in $\mathbb{P}^2$. All the other curves are non-singular rational curves.

2) Let C_j be an irreducible component of C such that $P \in C_j$ and with multiplicity $n \geq 1$ at P. After blowing-up at P, the new self-intersection of the (strict transform of the) curve C_j in the (strict transform of the) surface $\tilde{V}$ is $C_j^2 - n^2$. In this way one constructs the minimal good resolution graph Γ of $(V, 0)$.

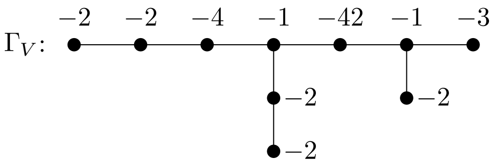
In particular the theory of hypersurface superisolated surface singularities "contains" in a canonical way the theory of complex projective plane curves.

Example 3.2. If $(V, 0) \subset (\mathbb{C}^3, 0)$ is a SIS with an irreducible tangent cone $C \subset \mathbb{P}^2$ then L_V is a rational homology sphere if and only if C is a rational curve and each of its singularities (C, p) is locally irreducible, i.e a cusp.

Example 3.3. For instance, if $f = f_6 + z^7$ is given by the equation $f_6 = (xz - y^2)^3 - ((y - x)x^2)^2$. The plane projective curve C defined by $f_6 = 0$ is irreducible with two singular points: $P_1 = [0 : 0 : 1]$ (with a singularity of local singularity type $u^3 - v^{10}$) and $P_2 = [1 : 1 : 1]$ (with a singularity of local singularity type $\mathbb{A}_2$) which are locally irreducible. Let $\pi : X \to \mathbb{P}^2$ be the minimal embedded resolution of C at its singular points P_1, P_2. Let $E_i, i \in I$, be the irreducible components of the divisor $\pi^{-1}(f^{-1}\{0\})$.



The minimal good resolution graph Γ_V of the superisolated singularity $(V, 0)$ is given by



3.3. The embedded resolution of a SIS

In [2], the first author has studied, for SIS, the Mixed Hodge Structure of the cohomology of the Milnor fibre introduced by Steenbrink and Varchenko, [28], [29]. For that he constructed in an effective way an embedded resolution of a SIS and described the MHS in geometric terms depending on invariants of the pair $(\mathbb{P}^2, C)$.

The first author determined the Jordan form of the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$ of a SIS. Let $\Delta_V(t)$ be the corresponding characteristic polynomial of the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$. Denote by $\mu(V, 0) = \deg(\Delta_V(t))$ the Milnor number of $(V, 0) \subset (\mathbb{C}^3, 0)$.

Let $\Delta^P(t)$ be the characteristic polynomial (or Alexander polynomial) of the action of the complex monodromy of the germ (C, P) on $H_1(F_{g^P}, \mathbb{C})$, (where g^P is a local equation of C at P and F_{g^P} denotes the corresponding Milnor fiber). Let μ^P be the Milnor number of C at P. Recall that if $n^P : \tilde{C}^P \to (C, P)$ is the normalization map then $\mu^P = 2\delta^P - (r^P - 1)$, where $\delta^P := \dim_{\mathbb{C}} n_*^P(\mathcal{O}_{\tilde{C}^P})/\mathcal{O}_{C,P}$ and r^P is the number of local irreducible components of C at P.

Let H be a $\mathbb{C}$-vector space and $\varphi : H \to H$ an endomorphism of H. The i-th Jordan polynomial of φ, denoted by $\Delta_i(t)$, is the monic polynomial such that for each $\zeta \in \mathbb{C}$, the multiplicity of ζ as a root of $\Delta_i(t)$ is equal to the number of Jordan blocks of size $i + 1$ with eigenvalue equal to ζ.

Let Δ_1 and Δ_2 be the first and the second Jordan polynomials of the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$ of V and let Δ_1^P be the first Jordan polynomial of the complex monodromy of the local plane singularity (C, P). After the Monodromy Theorem these polynomials joint with $\Delta_V(t)$ and Δ^P, $P \in \mathrm{Sing}(C)$, determine the corresponding Jordan form of the complex monodromy. Let us denote the Alexander polynomial of the plane curve C in $\mathbb{P}^2$ by $\Delta_C(t)$, it was introduced by A. Libgober [13, 14] and F. Loeser and Vaquié [16].

Theorem 3.4 [2]. *Let $(V, 0)$ be a SIS whose tangent cone $C = C_1 \cup \ldots \cup C_r$ has r irreducible components and degree d. Then the Jordan form of the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$ is determined by the following polynomials*

(i) *The characteristic polynomial $\Delta_V(t)$ is equal to*

$$\Delta_V(t) = \frac{(t^d - 1)^{\chi(\mathbb{P}^2 \setminus C)}}{(t - 1)} \prod_{P \in \mathrm{Sing}(C)} \Delta^P(t^{d+1}).$$

(ii) *The first Jordan polynomial is equal to*

$$\Delta_1(t) = \frac{1}{\Delta_C(t)(t-1)^{r-1}} \prod_{P\in \mathrm{Sing}(C)} \frac{\Delta_1^P(t^{d+1})\Delta_{(d)}^P(t)}{\Delta_{1,(d)}^P(t)^3},$$

where $\Delta_{(d)}^P(t) := \gcd(\Delta^P(t), (t^d-1)^{\mu^P})$ *and* $\Delta_{1,(d)}^P(t) := \gcd(\Delta_1^P(t), (t^d-1)^{\mu^P})$.

(iii) *The second Jordan polynomial is equal to*

$$\Delta_2(t) = \prod_{P\in \mathrm{Sing}(C)} \Delta_{1,(d)}^P(t).$$

Corollary 3.5 [2, Corollaire 5.5.4]. *The number of Jordan blocks of size* 2 *for the eigenvalue* 1 *of the complex monodromy* h *is equal to*

$$\sum_{P\in \mathrm{Sing}(C)} (r^P-1)-(r-1). \tag{3.1}$$

Let $\tilde{D}_i$ be the normalization of D_i and $\tilde{C}$ the disjoint union of the $\tilde{D}_i$ and $n: \tilde{C} \to C$ be the projection map. Thus the first Betti number of $\tilde{C}$ is $2g := 2\sum_i g(D_i)$ and the first Betti number of C is $2g + \sum_{P\in \mathrm{Sing}(C)}(r^P-1) - r + 1$. Then $\sum_{P\in \mathrm{Sing}(C)}(r^P-1)-(r-1)$ is exactly the difference between the first Betti numbers of C and $\tilde{C}$. In fact this non-negative integer is equal to the first Betti number of the minimal embedded resolution graph Γ_C of the projective plane curve C in $\mathbb{P}^2$, which is nothing but rank $H_1(\Gamma_V)$.

Corollary 3.6. *Let* $(V,0)$ *be a SIS whose tangent cone* $C = C_1 \cup \ldots \cup C_r$ *has* r *irreducible components. Then the number of independent cycles* $c(E) =$ rank $H_1(\Gamma_V) = \sum_{P\in \mathrm{Sing}(C)}(r^P-1)-(r-1)$.

In particular E *has no cycles if and only if* $\sum_{P\in \mathrm{Sing}(C)}(r^P-1) = (r-1)$ *if and only if the complex monodromy* h *has no Jordan blocks of size* 2 *for the eigenvalue* 1.

Corollary 3.7 [2, Corollaire 4.3.2]. *If for every* $P \in \mathrm{Sing}(C)$*, the local monodromy of the local plane curve equation* g^p *at* P *acting on the homology* $H_1(F_{g^P}, \mathbb{C})$ *of the Milnor fibre* F_{g^P} *has no Jordan blocks of maximal size* 2 *then the corresponding SIS has no Jordan blocks of size 3.*

Corollary 3.8. *Let* $(V,0) \subset (\mathbb{C}^3,0)$ *be a SIS with a rational irreducible tangent cone* $C \subset \mathbb{P}^2$ *of degree* d *whose singularities are locally irreducible. Then:*

(i) *the link* L_V *is a* $\mathbb{Q}$*HS link and* E *has no cycles,*
(ii) *the complex monodromy on* $H_2(F_{f,0},\mathbb{C})$ *has no Jordan blocks of size* 2 *for the eigenvalue* 1,

(iii) *the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$ has no Jordan blocks of size 3.*
(iv) *The first Jordan polynomial is equal to*

$$\Delta_1(t) = \frac{1}{\Delta_C(t)} \prod_{P \in \mathrm{Sing}(C)} \gcd(\Delta^P(t), (t^d - 1)^{\mu^P}).$$

The proof follows from the previous description and the fact that if every $P \in \mathrm{Sing}(C)$ is locally irreducible then by Lê D.T. result (see 2.2) the plane curve singularity has finite order and $\Delta_1^P(t) = 1$.

Corollary 3.9. *Let $(V, 0) \subset (\mathbb{C}^3, 0)$ be a SIS whose tangent cone $C = C_1 \cup \ldots \cup C_r$ has r irreducible components. Assume that $\sum_{P \in \mathrm{Sing}(C)} (r^P - 1) = (r - 1)$, then:*

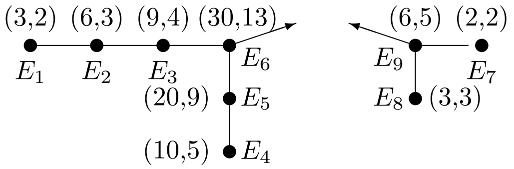
(i) *E has no cycles,*
(ii) *the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$ has no Jordan blocks of size 2 for the eigenvalue 1,*
(iii) *the complex monodromy on $H_2(F_{f,0}, \mathbb{C})$ has no Jordan blocks of size 3.*
(iv) *The first Jordan polynomial is equal to*

$$\Delta_1(t) = \frac{1}{\Delta_C(t)(t-1)^{r-1}} \prod_{P \in \mathrm{Sing}(C)} \gcd(\Delta^P(t), (t^d - 1)^{\mu^P}).$$

The proof follows from Corollary 3.6 and the part (e) Monodromy Theorem 2.2.

3.4. The first Jordan polynomial in Example 3.3

As we described above, the plane projective curve C defined by $f_6 = (xz - y^2)^3 - ((y - x)x^2)^3 = 0$ is irreducible, rational and with two singular points: $P_1 = [0 : 0 : 1]$ (with a singularity of local singularity type $u^3 - v^{10}$) and $P_2 = [1 : 1 : 1]$ (with a singularity of local singularity type $\mathbb{A}_2$) which are unibranched. Let $\pi : X \to \mathbb{P}^2$ be the minimal embedded resolution of C at its singular points P_1, P_2. Let E_i, $i \in I$, be the irreducible components of the divisor $\pi^{-1}(f^{-1}\{0\})$. For each $j \in I$, we denote by N_j the multiplicity of E_j in the divisor of the function $f \circ \pi$ and we denote by $\nu_j - 1$ the multiplicity of E_j in the divisor of $\pi^*(\omega)$ where ω is the non-vanishing holomorpic 2-form $dx \wedge dy$ in $\mathbb{C}^2 = \mathbb{P}^2 \setminus L_\infty$. Then the divisor $\pi^*(C)$ is a normal crossing divisor. We attach to each exceptional divisor E_i its numerical data (N_i, ν_i).



Thus $\Delta^{P_1}(t) = \frac{(t-1)(t^{30}-1)}{(t^3-1)(t^{10}-1)} = \phi_{30}\phi_{15}\phi_6$ and $\Delta^{P_2}(t) = \frac{(t-1)(t^6-1)}{(t^3-1)(t^2-1)} = \phi_6$, where ϕ_k is the k-th cyclotomic polynomial. Thus, by Corollary 3.8, the only possible eigenvalues of with Jordan blocks of size 2 are the roots of the polynomial $\Delta_1(t) = \frac{\phi_6^2}{\Delta_C(t)}$.

The proof of our main result will be finished if we show that the Alexander polynomial $\Delta_C(t) = \phi_6$. The Alexander polynomial, in particular of sextics, has been investigated in detail by Artal [1], Artal and Carmona [3], Degtyarev [6], Oka [24], Pho [25], Zariski [30] among others. In [23] Corollary 18, I.2, it is proved that $\Delta_C(t) = \phi_6$.

Consider a generic line L_∞ in $\mathbb{P}^2$, in our example the line $z = 0$ is generic, and define $f(x, y) = f_6(x, y, 1)$. Consider the (global) Milnor fibration given by the homogeneous polynomial $f_6 : \mathbb{C}^3 \to \mathbb{C}$ with Milnor fibre F. Randell [26] proved that $\Delta_C(t)(t-1)^{r-1}$ is the characteristic polynomial of the algebraic monodromy acting on $F : T_1 : H_1(F, \mathbb{C}) \to H_1(F, \mathbb{C})$.

Lemma 3.10 (Divisibility properties) [13]. *The Alexander polinomial $\Delta_C(t)(t-1)^{r-1}$ divides $\prod_{P\in \mathrm{Sing}(C)} \Delta^P(t)$ and the Alexander polynomial at infinity $(t^d-1)^{d-2}(t-1)$. In particular the roots of the Alexander polynomial are d-roots of unity.*

To compute the Alexander polynomial $\Delta_C(t)$ we combined the method described in [1] with the methods given in [13], [16] and [9].

Consider for $k = 1, \ldots, d-1$ the ideal sheaf $\mathcal{I}^k$ on $\mathbb{P}^2$ defined as follows:

- If $Q \in \mathbb{P}^2 \setminus \mathrm{Sing}(C)$ then $\mathcal{I}^k_Q = \mathcal{O}_{\mathbb{P}^2,Q}$.
- If $P \in \mathrm{Sing}(C)$ then $\mathcal{I}^k_P$ is the following ideal of $\mathcal{O}_{\mathbb{P}^2,P}$: if $h \in \mathcal{O}_{\mathbb{P}^2,P}$ then $h \in \mathcal{I}^k_P$ if and only if the vanishing order of $\pi^*(h)$ along each E_i is, at least, $-(\nu_i - 1) + [\frac{kN_i}{d}]$ (where [.] stands for the integer part of a real number).

For $k \geq 0$ the following map

$$\sigma_k : H^0(\mathbb{P}^2, \mathcal{O}_{\mathbb{P}^2}(k-3)) \to \bigoplus_{P\in \mathrm{Sing}(C)} \mathcal{O}_{\mathbb{P}^2,P}/\mathcal{I}^k_P : h \mapsto (h_P + \mathcal{I}^k_P)_{P\in \mathrm{Sing}(C)}$$

is well defined (up to scalars) and the result of [13] and [16] reinterpreted in this language as [1] and [9] reads as follows: