
**CASTELNUOVO-MUMFORD REGULARITY OF THE FIBER CONE
FOR GOOD FILTRATIONS**

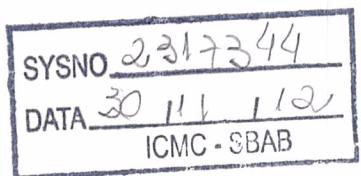
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Castelnuovo-Mumford Regularity of the Fiber Cone for good filtrations

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Abstract

In this paper we show that there is a close relationship between the invariants characterizing the homogeneous vanishing of the local cohomology of the Rees algebra and the associated graded ring for good filtration case. We obtain relationships between the Castelnuovo-Mumford regularity of the fiber cone, associated graded ring, Rees algebra and reduction number for the good filtration case.

1 Introduction

Let (A, \mathfrak{m}) be a commutative Noetherian local ring and $\mathfrak{F} : A \supset I \supset I^2 \supset \dots$ a adic-filtration. Then we have important graded algebras, namely, $R(I) := \bigoplus_{n \geq 0} I^n t^n$, the associated graded ring, $G(I) := \bigoplus_{n \geq 0} I^n / I^{n+1}$ and the fiber cone, $F(I) := \bigoplus_{n \geq 0} I^n / \mathfrak{m} I^n = R(I) / \mathfrak{m} R(I)$. In the papers [CZ1], [CZ2] and [CZ], Cortadellas and Zarzuela, studied the depth properties of the fiber cone by using certain graded modules associated to filtration of modules. Jayanthan and Nanduri, in [JN], used some results of those articles to study the regularity of the fiber cone.

The Castelnuovo-Mumford regularity of $R(I)$ and $G(I)$ are very known ([HZ], [O], [H], [T], [JU], etc). In the paper [HZ], for example, Hoa and Zarzuela obtain many results between reduction number and a -invariant of good filtrations. Ooishi, in [O], proved that the regularity of $R(I)$ and $G(I)$

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are equal. This formula was also discovered by Johnson and Ulrich [JU]. After, in [T], Trung studied the relationships between the Rees algebra and the associated graded ring, and then, he also concluded that for any ideal in a Noetherian local ring, the regularity of $R(I)$ and $G(I)$ are equal. We show this same equality for the good filtration case.

For the I -adic case, Jayanthan and Nanduri [JN] prove that for any ideal of analytic spread one in a Noetherian local ring, the regularity of the fiber cone is bounded by the regularity of the associated graded ring. Moreover, they obtain on certain conditions that in fact the equality holds. The goal in this paper is to give an analogous theory on regularity of the fiber cone, Rees algebra, associated graded ring and reduction number for good filtration case. We show that the regularity of the fiber cone for good filtration case behave well as in the I -adic case.

The paper is divided into three parts. In section 2 we introduce the basic concepts about good filtration, reduction and regularity. In the section 3 we extend the Theorem 3.1, Corollary 3.2 and Corollary 3.3 of Trung [T] for the good filtration case. In section 4, we obtain relationship between the regularities of the fiber cone, the associated graded ring, Rees algebra and reduction number for the good filtration case. The results of this section generalize the results of the section 2 in [JN].

2 Preliminaries

A sequence $\mathfrak{F} = (I_n)_{n \geq 0}$ of ideals of A is called a *filtration* of A if $I_0 = A \supseteq I_1 \supseteq I_2 \supseteq I_3 \supseteq \dots$, $I_1 \neq A$ and $I_i I_j \subseteq I_{i+j}$ for all $i, j \geq 0$.

Let I be an ideal of A . \mathfrak{F} is called an I -*good filtration* if $II_i \subseteq I_{i+1}$ for all $i \geq 0$ and $I_{n+1} = II_n$ for all $n \gg 0$. \mathfrak{F} is called a *good filtration* if it is an I -good filtration for some ideal I of A . \mathfrak{F} is a good-filtration if and only if it is a I_1 -good filtration.

Given any filtration \mathfrak{F} we can construct the following two graded rings

$$R(\mathfrak{F}) = A \oplus I_1 t \oplus I_2 t^2 \oplus \dots, \quad G(\mathfrak{F}) = A/I_1 \oplus I_1/I_2 \oplus I_2/I_3 \oplus \dots$$

We call $R(\mathfrak{F})$ the *Rees algebra* of \mathfrak{F} and $G(\mathfrak{F})$ the *associated graded ring* of \mathfrak{F} . We also denote $G(\mathfrak{F})_+ = \bigoplus_{n \geq 1} I_n/I_{n+1}$. If \mathfrak{F} is an I -adic filtration, i.e, $\mathfrak{F} = (I^n)_{n \geq 0}$ for some ideal I , we denote $R(\mathfrak{F})$ and $G(\mathfrak{F})$ by $R(I)$ and $G(I)$ respectively. A filtration \mathfrak{F} is called *Noetherian* if $R(\mathfrak{F})$ is a Noetherian

ring. Noetherian filtration satisfies $\cap_{n \geq 0} I_n = 0$. By adapting the proof of [M, Theorem 15.7], we can prove that if \mathfrak{F} is Noetherian then $\dim G(\mathfrak{F}) = \dim A$.

For any filtration $\mathfrak{F} = (I_n)$ and any ideal J of A , we let \mathfrak{F}/J denote the filtration $((I_n + J)/J)_n$ in the ring A/J . Of course that if \mathfrak{F} is Noetherian then \mathfrak{F}/J so is.

A *reduction* of a filtration \mathfrak{F} is an ideal $J \subseteq I_1$ such that $J I_n = I_{n+1}$ for $n \gg 0$. We also know that $J \subseteq I_1$ is a reduction of \mathfrak{F} if and only if $R(\mathfrak{F})$ is a finite $R(J)$ -module. By [B, Theorem III.3.1.1 and Corollary III.3.1.4], $R(\mathfrak{F})$ is a finite $R(J)$ -module if and only if there exists an integer k such that $I_n \subseteq (I_1)^{n-k}$ for all n . A *minimal reduction* of \mathfrak{F} is a reduction of \mathfrak{F} minimal with respect to containment. A good filtration \mathfrak{F} is called *equimultiple* if I_1 is equimultiple, i.e., $s(I_1) = \text{ht } I_1$.

If J is a reduction of the I -adic filtration, we say simply that J is a reduction of I . By [NR], minimal reduction of ideals always exist. If $R(\mathfrak{F})$ is a $R(I_1)$ -module, then J is a reduction of \mathfrak{F} if and only if J is a reduction of I_1 . Thus minimal reductions of good filtration always exist. For minimal reduction J of \mathfrak{F} we set $r_J(\mathfrak{F}) = \sup\{n \in \mathbb{Z} \mid I_n \neq J I_{n-1}\}$. The *reduction number* of \mathfrak{F} is defined as $r(\mathfrak{F}) = \min\{r_J(\mathfrak{F}) \mid J \text{ is minimal reduction of } \mathfrak{F}\}$. Let \mathfrak{F} be a Noetherian filtration. For any element $x \in I_1$ we let x^* denote the image of x in $G(\mathfrak{F})_1 = I_1/I_2$ and x^o denote the image of x in $F(\mathfrak{F})_1 = I_1/\mathfrak{m}I_1$. If x^* is a regular element of $G(\mathfrak{F})$ then x is a regular element of A and by the [HZ, Lemma 3.4], $G(\mathfrak{F}/(x)) \cong G(\mathfrak{F})/(x^*)$.

An element $x \in I_1$ is called *superficial* for \mathfrak{F} if there exists an integer c such that $(I_{n+1} : x) \cap I_c = I_n$ for all $n \geq c$. By [HZ, Remark 2.10], an element x is superficial for \mathfrak{F} if and only if $(0 :_{G(\mathfrak{F})} x^*)_n = 0$ for all sufficiently large. If $\text{grade } I_1 \geq 1$ and x is superficial for \mathfrak{F} then x is a regular element of A . To see that, let suppose that x is not a zero-divisor. Thus if $ux = 0$ then $(I_1)^c u \subseteq \cap_n ((I_n : x) \cap I_c) = \cap_n I_n = 0$. Hence $u = 0$.

A sequence x_1, \dots, x_k is called a *superficial sequence* for \mathfrak{F} if x_1 is superficial for \mathfrak{F} and x_i is superficial for $\mathfrak{F}/(x_1, \dots, x_{i-1})$ for $2 \leq i \leq k$.

Let f_1, \dots, f_r be a sequence of homogeneous elements of a noetherian graded algebra $S = \bigoplus_{n \geq 0} S_n$ over a local ring S_0 . It is called *filter-regular sequence* of S if $f_i \notin \mathfrak{p}$ for all primes $\mathfrak{p} \in \text{Ass}(S/(f_1, \dots, f_{i-1}))$ such that $S_+ \not\subseteq \mathfrak{p}$, $i = 1, \dots, r$.

Let (A, \mathfrak{m}) be a local ring and \mathfrak{F} a good filtration. Then $v_1, \dots, v_t \in I_1$ are *analytically independent* in \mathfrak{F} if and only if, whenever $h \in \mathbb{N}$ and $f \in A[X_1, \dots, X_t]$ (the ring of polynomials over A in t indeterminates) is a homogeneous polynomial of degree h such that $f(v_1, \dots, v_t) \in I_h \mathfrak{m}$, then

all coefficients of f lie in \mathfrak{m} . Moreover, if $v_1, \dots, v_t \in I_1$ are analytically independent in \mathfrak{F} , and $J = (v_1, \dots, v_t)$, then $J^h \cap I_h \mathfrak{m} = J^h \mathfrak{m}$ for all $h \in \mathbb{N}$.

Now let define the analytic spread of a filtration \mathfrak{F} . The number $s = s(\mathfrak{F}) = \dim R(\mathfrak{F})/\mathfrak{m}R(\mathfrak{F})$ [HZ] is said to be the *analytic spread* of \mathfrak{F} . Thus, when \mathfrak{F} is the I -adic filtration, the analytic spread $s(I)$ equals $s(\mathfrak{F})$. Rees introduced the notion of basic reductions of Noetherian filtrations and he showed in [R, Theorem 6.12] that $s(\mathfrak{F})$ equals the minimal number of generators of any minimal reduction. By [HZ, Lemma 2.7], $s(\mathfrak{F}) = \dim G(\mathfrak{F})/\mathfrak{m}G(\mathfrak{F})$ and by [HZ, Lemma 2.8], $s(\mathfrak{F}) = s(I_1)$.

Let $S = \bigoplus_{n \geq 0} S_n$ be a finitely generated standard graded ring over a Noetherian commutative ring S_0 . For any graded S -module M we denote by M_n the homogeneous part of degree n of M and we define

$$a(M) := \begin{cases} \max\{n \mid M_n \neq 0\} & \text{if } M \neq 0 \\ -\infty & \text{if } M = 0 \end{cases}$$

Let S_+ be the ideal generated by the homogeneous elements of positive degree of S . For $i \geq 0$, set

$$a_i(S) := a(H_{S_+}^i(S)),$$

where $H_{S_+}^i(\cdot)$ denotes the i -th local cohomology functor with respect to the ideal S_+ . More generally, for $i \geq 0$ and any graded S -module M , set

$$a_i(M) := a(H_{S_+}^i(M)),$$

where $H_{S_+}^i(M)$ denotes the i -th local cohomology module of M with respect to the irrelevant ideal S_+ . The *Castelnuovo-Mumford regularity* (or simply *regularity*) of M is defined as the number

$$\text{reg}(M) := \max\{a_i(M) + i \mid i \geq 0\}.$$

When $M = S$, the regularity $\text{reg } S$ is an important invariant of the graded ring S , [EG] and [O2].

3 Regularity of the Rees Algebra and the Associated Graded Ring for good filtrations

In the paper [T], Trung showed that there is a close relationship between the invariants characterizing the homogeneous vanishing of the local cohomology of the Rees algebra and the associated graded ring of an ideal. In

1987, Oishi proved in [O] that the Castelnuovo-Mumford regularity of the associated graded ring and the associated graded ring of an ideal are equal, i.e, $\text{reg } G(I) = \text{reg } R(I)$. In 1996, Johnson and Ulrich [JU] rediscovered this equality. After that, Trung [T] also showed this equality in a Corollary. In this section we obtain generalizations of these results for good filtration case.

Let \mathfrak{F} a filtration over a ring A . We consider the ring A as a graded ring concentrated in degree zero. Now, consider the following exact sequences

$$0 \rightarrow R(\mathfrak{F})_+ \rightarrow R(\mathfrak{F}) \rightarrow A \rightarrow 0; \quad (3.1)$$

$$0 \rightarrow R(\mathfrak{F})_+(1) \rightarrow R(\mathfrak{F}) \rightarrow G(\mathfrak{F}) \rightarrow 0. \quad (3.2)$$

Lemma 3.1. *Let \mathfrak{F} a filtration over a ring A . We have*

$$H_{R(\mathfrak{F})_+}^i(R(\mathfrak{F}))_n = 0 \text{ para } n \geq \max\{0, a_i(G(\mathfrak{F})) + 1\} \text{ if } i = 0, 1$$

and for $n \geq a_i(G(\mathfrak{F})) + 1$ if $i \geq 2$.

Proof. We denote $H^i(\cdot) = H_{R(\mathfrak{F})_+}^i(\cdot)$. As $H^0(A) = A$ and $H^i(A) = 0$ for $i \geq 1$, from the exact sequence (3.1) we have

$$H^i(R(\mathfrak{F})_+)_n \simeq H^i(R(\mathfrak{F}))_n \text{ for } n = 0, i \geq 2, \text{ and for } n \neq 0, i \geq 0. \quad (3.3)$$

As $H_{G(\mathfrak{F})_+}^i(G(\mathfrak{F})) = H^i(G(\mathfrak{F}))$, the exact sequence (3.2) induces the long exact sequence

$$H^i(R(\mathfrak{F})_+)_n \rightarrow H^i(R(\mathfrak{F}))_n \rightarrow H^i(G(\mathfrak{F}))_n \rightarrow H^{i+1}(R(\mathfrak{F})_+)_n.$$

Then we have a surjective map

$$H^i(R(\mathfrak{F})_+)_n \rightarrow H_i(R(\mathfrak{F}))_n \text{ for } n \geq \max\{0, a_i(G(\mathfrak{F})) + 1\} \text{ if } i = 0, 1$$

and for $n \geq a_i(G(\mathfrak{F})) + 1$ if $i \geq 2$.

By the fact that $H^i(R(\mathfrak{F}))_n = 0$ for $n \gg 0$, we can conclude

$$H^i(R(\mathfrak{F}))_n = 0 \text{ for } n \geq \max\{0, a_i(G(\mathfrak{F})) + 1\} \text{ if } i = 0, 1 \quad (3.4)$$

and for $n \geq a_i(G(\mathfrak{F})) + 1$ if $i \geq 2$.

□

Theorem 3.2. *Let \mathfrak{F} a filtration over a ring A . Then*

- (i) $a_i(R(\mathfrak{F})) \leq a_i(G(\mathfrak{F}))$, $i \neq 1$;
- (ii) $a_i(R(\mathfrak{F})) = a_i(G(\mathfrak{F}))$ if $a_i(G(\mathfrak{F})) \geq a_{i+1}(G(\mathfrak{F}))$, $i \neq 1$;
- (iii) The statements (i) and (ii) are true for $i = 1$ if $H_{G(\mathfrak{F})_+}^1(G(\mathfrak{F})) \neq 0$ or if $I_1 \subseteq \sqrt{0}$;
- (iv) $a_1(R(\mathfrak{F})) = -1$ if $H_{G(\mathfrak{F})_+}^1(G(\mathfrak{F})) = 0$ and $I_1 \not\subseteq \sqrt{0}$;

Proof. We denote $H^i(\cdot) = H_{R(\mathfrak{F})_+}^i(\cdot)$. From Lemma above, $a_i(R(\mathfrak{F})) \leq a_i(G(\mathfrak{F}))$ for $i \geq 2$. For $i = 0$, we have two cases. If $H^0(G(\mathfrak{F})) = 0$, $a_0(G(\mathfrak{F})) = -\infty$. Hence, by using the Lemma 3.1, $H^0(R(\mathfrak{F}))_n = 0$ para $n \geq 0$. But $H^0(R(\mathfrak{F})) \subseteq R(\mathfrak{F})$ is a ideal, then $H^0(R(\mathfrak{F})) = 0$. It follow that $a_0(R(\mathfrak{F})) = a_0(G(\mathfrak{F})) = -\infty$. If $H^0(G(\mathfrak{F}))_n \neq 0$, since $H^0(G(\mathfrak{F})) \subseteq G(\mathfrak{F})$ is a ideal, $a_0(G(\mathfrak{F})) \geq 0$. Hence by the Lemma 3.1,

$$H^0(R(\mathfrak{F}))_n = 0 \text{ for } n \geq a_0(G(\mathfrak{F})) + 1.$$

It implies $a_0(R(\mathfrak{F})) \leq a_0(G(\mathfrak{F}))$. (i) is proved.

Let show (ii): By using (i), it is enough to show $a_i(R(\mathfrak{F})) \geq a_i(G(\mathfrak{F}))$. Clearly we can suppose $a_i(G(\mathfrak{F})) \neq -\infty$. If $i = 0$, $H^0(G(\mathfrak{F})) \neq 0$ and then $a_0(G(\mathfrak{F})) \geq 0$. Due to (3.2) and (3.3),

$$H^0(R(\mathfrak{F}))_{a_0(G(\mathfrak{F}))} \rightarrow H^0(G(\mathfrak{F}))_{a_0(G(\mathfrak{F}))} \rightarrow H^1(R(\mathfrak{F}))_{a_0(G(\mathfrak{F}))+1}.$$

By the Lemma 3.1, we have either $a_1(G(\mathfrak{F})) \leq -1$ or $a_1(R(\mathfrak{F})) \leq a_1(G(\mathfrak{F}))$. In the first case, since $a_0(G(\mathfrak{F})) \geq 0 > -1 \geq a_1(R(\mathfrak{F}))$, $H^1(R(\mathfrak{F}))_{a_0(G(\mathfrak{F}))+1} = 0$. Then

$$H^0(R(\mathfrak{F}))_{a_0(G(\mathfrak{F}))} \rightarrow H^0(G(\mathfrak{F}))_{a_0(G(\mathfrak{F}))} \rightarrow 0.$$

Since $H^0(G(\mathfrak{F}))_{a_0(G(\mathfrak{F}))} \neq 0$, it follows that $H^0(R(\mathfrak{F}))_{a_0(G(\mathfrak{F}))} \neq 0$, i.e, $a_0(R(\mathfrak{F})) \geq a_0(G(\mathfrak{F}))$. For the second case by using the hypothesis $a_0(G(\mathfrak{F})) \geq a_1(G(\mathfrak{F}))$ we have $a_1(R(\mathfrak{F})) \leq a_0(G(\mathfrak{F}))$ so that $H^1(R(\mathfrak{F}))_{a_0(G(\mathfrak{F}))+1} = 0$. It follows similarly to first case that $a_0(R(\mathfrak{F})) \geq a_0(G(\mathfrak{F}))$. Now if $i \geq 1$, by (i), $a_{i+1}(G(\mathfrak{F})) \geq a_{i+1}(R(\mathfrak{F}))$. From hypothesis, $a_{i+1}(R(\mathfrak{F})) \leq a_i(G(\mathfrak{F}))$. Then

$$H^{i+1}(R(\mathfrak{F})_+)_{{a_i(G(\mathfrak{F}))}+1} \simeq H^{i+1}(R(\mathfrak{F}))_{{a_i(G(\mathfrak{F}))}+1} = 0.$$

From the exact sequence (3.2), we have a surjective map

$$H^i(R(\mathfrak{F}))_{{a_i(G(\mathfrak{F}))}} \rightarrow H^i(G(\mathfrak{F}))_{{a_i(G(\mathfrak{F}))}}.$$



Since $H^i(G(\mathfrak{F}))_{a_i(G(\mathfrak{F}))} \neq 0$, $H^i(R(\mathfrak{F}))_{a_i(G(\mathfrak{F}))} \neq 0$, i.e, $a_i(R(\mathfrak{F})) \geq a_i(G(\mathfrak{F}))$.

Now let prove (iii). If $H^1_{G(\mathfrak{F})_+}(G(\mathfrak{F})) \neq 0$. By [T, Corollary 2.3(iii)] $a_1(G(\mathfrak{F})) + 1 \geq 0$. Hence by using Lemma 3.1, $H^1(R(\mathfrak{F}))_n = 0$ for $n \geq a_1(G(\mathfrak{F})) + 1$. Then $a_1(R(\mathfrak{F})) \leq a_1(G(\mathfrak{F}))$.

If $I_1 \subseteq \sqrt{0}$, $R(\mathfrak{F})_+ \subseteq \sqrt{0}$ and $G(\mathfrak{F})_+ \subseteq \sqrt{0}$. We have $\text{ara}(R(\mathfrak{F})_+) = \text{ara}(\sqrt{R(\mathfrak{F})_+}) = \text{ara}(\sqrt{0}) = 0$. Similarly, $\text{ara}(G(\mathfrak{F})_+) = 0$. By [BS, Corollary 3.3.3],

$$H^i(R(\mathfrak{F})) = 0 \text{ for } i > \text{ara}(R(\mathfrak{F})) = 0$$

and

$$H^i(G(\mathfrak{F})) = 0 \text{ for } i > \text{ara}(G(\mathfrak{F})) = 0.$$

In particular $a_1(R(\mathfrak{F})) = a_1(G(\mathfrak{F})) = -\infty$.

Now, let prove (iv). By the hypothesis, $H^1(G(\mathfrak{F})) = 0$ and $I_1 \not\subseteq \sqrt{0}$. Then $a_1(G(\mathfrak{F})) = -\infty$. By the Lemma 3.1, $a_1(R(\mathfrak{F})) \leq -1$. Let suppose that $a_1(R(\mathfrak{F})) < -1$. Then $H^1(R(\mathfrak{F}))_{-1} = 0$. As $H^0(G(\mathfrak{F}))_{-1} = 0$ since $H^0(G(\mathfrak{F})) \subseteq G(\mathfrak{F})$. It follow that

$$H^0(G(\mathfrak{F}))_{-1} \rightarrow H^1(R(\mathfrak{F})_+)_0 \rightarrow H^1(R(\mathfrak{F}))_{-1}.$$

Then $H^1(R(\mathfrak{F})_+)_0 = 0$. From the exact sequence (3.1),

$$H^0(R(\mathfrak{F})_+)_0 \rightarrow H^0(R(\mathfrak{F}))_0 \rightarrow H^0(A) \rightarrow 0.$$

But $H^0(R(\mathfrak{F})_+) \subseteq R(\mathfrak{F})_+$ and $(R(\mathfrak{F})_+)_0 = 0$. Then $H^0(R(\mathfrak{F})_+)_0 = 0$. It is easy to show $H^0(R(\mathfrak{F}))_0 = H^0_{I_1}(A)$. We also know that $H^0(A) = A$. From exact sequence above $H^0_{I_1}(A) = A$ and this implies that $I_1^n = 0$ for some $n \geq 1$. By hypothesis it is a contradiction. Therefore $a_1(R(\mathfrak{F})) = -1$. \square

Corollary 3.3. Define $\ell := \max\{i : H^i_{G(\mathfrak{F})_+}(G(\mathfrak{F})) \neq 0\}$. Then

- (i) $a_\ell(R(\mathfrak{F})) = a_\ell(G(\mathfrak{F}))$
- (ii) $\ell = \max\{i : H^i_{R(\mathfrak{F})_+}(R(\mathfrak{F})) \neq 0\}$ if $I_1 \subseteq \sqrt{0}$ or $\ell \geq 1$.

Proof. For $i \geq \ell$ we have $a_{i+1}(G(\mathfrak{F})) = -\infty$. Thus we always have $a_i(G(\mathfrak{F})) \geq a_{i+1}(G(\mathfrak{F}))$.

If $i \neq 1$, by the Theorem 3.2, $a_i(R(\mathfrak{F})) = a_i(G(\mathfrak{F}))$. In this way, if $\ell > 1$, $a_\ell(R(\mathfrak{F})) = a_\ell(G(\mathfrak{F}))$. If $H^\ell_{R(\mathfrak{F})_+}(R(\mathfrak{F})) = 0$, $a_\ell(R(\mathfrak{F})) = -\infty$. Then $a_\ell(G(\mathfrak{F})) = -\infty$. A contradiction. Thus

$$H^\ell_{R(\mathfrak{F})_+}(R(\mathfrak{F})) \neq 0.$$

If there exist $j > \ell$ such that $H_{R(\mathfrak{F})_+}^j(R(\mathfrak{F})) \neq 0$ ($a_j(R(\mathfrak{F})) \neq -\infty$), by the Theorem 3.2(ii), $a_j(G(\mathfrak{F})) = a_j(R(\mathfrak{F}))$. A contradiction, since $H_{G(\mathfrak{F})_+}^j(G(\mathfrak{F})) = 0$. Therefore if $\ell > 1$,

$$\ell = \max\{i : H_{R(\mathfrak{F})_+}^i(R(\mathfrak{F})) \neq 0\}.$$

If $\ell = 1$, $H_{G(\mathfrak{F})_+}^1(G(\mathfrak{F})) \neq 0$. By the Theorem 3.2(iii), $a_1(R(\mathfrak{F})) = a_1(G(\mathfrak{F}))$. If $H_{R(\mathfrak{F})_+}^1(R(\mathfrak{F})) = 0$ then $a_1(R(\mathfrak{F})) = -\infty$. It implies $H_{G(\mathfrak{F})_+}^1(G(\mathfrak{F})) = 0$. A contradiction. Thus $H_{R(\mathfrak{F})_+}^1(R(\mathfrak{F})) \neq 0$. If there exist $j > 1$ such that $H_{R(\mathfrak{F})_+}^j(R(\mathfrak{F})) \neq 0$, by the Theorem 3.2(ii),

$$a_j(R(\mathfrak{F})) = a_j(G(\mathfrak{F})) \neq -\infty.$$

A contradiction.

Now let prove the last case. Let suppose $\ell = 0$ and $I_1 \subseteq \sqrt{0}$. From the Theorem 3.2(ii), $a_0(R(\mathfrak{F})) = a_0(G(\mathfrak{F}))$. If $H_{R(\mathfrak{F})_+}^0(R(\mathfrak{F})) = 0$ then $a_0(R(\mathfrak{F})) = -\infty$ and it implies that $H_{G(\mathfrak{F})_+}^0(G(\mathfrak{F})) = 0$. A contradiction. The rest is similar. \square

Corollary 3.4. *Let A a Noetherian local ring and \mathfrak{F} a good filtration. Then*

$$\operatorname{reg} R(\mathfrak{F}) = \operatorname{reg} G(\mathfrak{F}).$$

Proof. By the Theorem 3.2(i), $a_i(R(\mathfrak{F})) + i \leq a_i(G(\mathfrak{F})) + i$ for $i \neq 1$. By the Theorem 3.2(iii)(iv) either

$$a_1(R(\mathfrak{F})) + 1 \leq a_1(G(\mathfrak{F})) + 1 \text{ or } a_1(R(\mathfrak{F})) + 1 = 0 \leq \operatorname{reg} G(\mathfrak{F}).$$

In both case we have $\operatorname{reg} R(\mathfrak{F}) \leq \operatorname{reg} G(\mathfrak{F})$.

For the other inequality, first remember that by [HZ, Proposition 3.2], $\operatorname{reg} G(\mathfrak{F}) \geq 0$. Let i be maximal such that

$$a_i(G(\mathfrak{F})) + i = \operatorname{reg} G(\mathfrak{F}) \geq 0.$$

It implies that $a_i(G(\mathfrak{F})) + i \geq a_{i+1}(G(\mathfrak{F})) + i + 1$, i.e, $a_i(G(\mathfrak{F})) > a_{i+1}(G(\mathfrak{F}))$. If $H_{G(\mathfrak{F})_+}^i(G(\mathfrak{F})) = 0$ then $a_i(G(\mathfrak{F})) = -\infty$. A contradiction since $\operatorname{reg} G(\mathfrak{F}) \geq 0$. Thus

$$H_{G(\mathfrak{F})_+}^i(G(\mathfrak{F})) \neq 0.$$

If $i \neq 1$, by the Theorem 3.2(ii), $a_i(R(\mathfrak{F})) = a_i(G(\mathfrak{F}))$. If $i = 1$, by Theorem 3.2(iii), $a_1(R(\mathfrak{F})) = a_1(G(\mathfrak{F}))$ since $H_{G(\mathfrak{F})_+}^1(G(\mathfrak{F})) \neq 0$. Thus $a_i(R(\mathfrak{F})) = a_i(G(\mathfrak{F}))$ for $i \geq 0$. Therefore

$$\operatorname{reg} G(\mathfrak{F}) = a_i(R(\mathfrak{F})) + i \leq \operatorname{reg} R(\mathfrak{F}).$$

\square

4 Regularity of the Fiber Cone for good filtrations

In the previous section we have shown the relationship between the a -invariants and regularity of the associated graded ring $G(\mathfrak{F})$ and the Rees algebra $R(\mathfrak{F})$. It is natural asks when we have inequality or equality between the fiber cone $F(\mathfrak{F})$ and the Rees algebra $R(\mathfrak{F})$. In the article [JN], Jayanthan and Nanduri obtained, under some assumption, inequalities and equalities between the regularities of $F(I)$ and $R(I)$. The main aim this section is generalize the results of the second section of [JN] for good filtration case, that is, we search upper bound for the fiber cone $F(\mathfrak{F})$. The proofs are essentially the same.

Let A a Noetherian Local Ring of dimension $d > 0$ with an infinite residue field A/\mathfrak{m} and \mathfrak{F} a good-filtration. Consider the filtrations

$$\mathcal{F} : A \supset \mathfrak{m} \supset \mathfrak{m}I_1 \supset \mathfrak{m}I_2 \supset \dots$$

$$\mathfrak{F} : A \supset I_1 \supset I_2 \supset I_3 \supset \dots$$

Throughout we suppose that $\mathfrak{F} \leq \mathcal{F}$, i.e, $I_{n+1} \subseteq \mathfrak{m}I_n$. Hence $R(\mathcal{F})$ is a $R(\mathfrak{F})$ -module finitely generated since \mathfrak{F} is a reduction of \mathcal{F} . We have two exact sequences

$$0 \rightarrow R(\mathfrak{F}) \rightarrow R(\mathcal{F}) \rightarrow \mathfrak{m}G(\mathfrak{F})(-1) \rightarrow 0 \quad (4.1)$$

$$0 \rightarrow \mathfrak{m}G(\mathfrak{F}) \rightarrow G(\mathfrak{F}) \rightarrow F(\mathfrak{F}) \rightarrow 0 \quad (4.2)$$

of $R(\mathfrak{F})$ -modules finitely generated.

In this article we always consider $\ell := s(\mathfrak{F}) = \dim F(\mathfrak{F}) > 0$.

Lemma 4.1. *Let $\underline{x} = x_1, \dots, x_\ell$ generators of a minimal reduction \mathfrak{F} . We know that $\sqrt{R(\mathfrak{F})_+} = \sqrt{(x_1, \dots, x_\ell)}$. Denote $\underline{x}^k = (x_1^k, \dots, x_\ell^k)$. We have $a_\ell(R(\mathcal{F})) - 1 \leq a_\ell(R(\mathfrak{F}))$.*

Proof. By [HIO, Corollary 35.21],

$$[H_{R(\mathfrak{F})_+}^\ell(R(\mathfrak{F}))]_n \cong \varinjlim_k \frac{I_{\ell k+n}}{(\underline{x}_k)I_{(\ell-1)k+n}}$$

and

$$[H_{R(\mathfrak{F})_+}^\ell(R(\mathcal{F}))]_n \cong \varinjlim_k \frac{\mathfrak{m}I_{\ell k+n-1}}{(\underline{x}_k)\mathfrak{m}I_{(\ell-1)k+n-1}}.$$

Then $a_\ell(R(\mathcal{F})) - 1 \leq a_\ell(R(\mathfrak{F}))$. □

Lemma 4.2. *Let (A, \mathfrak{m}) a Noetherian local ring and \mathfrak{F} a good-filtration such that $s(\mathfrak{F}) = 1$. If J is a minimal reduction of \mathfrak{F} and $\text{grade } I_1 = 1$ then*

$$\text{reg } F(\mathfrak{F}) = r_J(\mathfrak{F}).$$

Proof. Since J is a minimal reduction of \mathfrak{F} , it follows by [R], that $s(\mathfrak{F}) = \mu(J)$. But by the hypothesis $s(\mathfrak{F}) = 1$, then $J = (a)$. By a adaptation of [BS, Proposition 18.2.4], a is independent analytically in \mathfrak{F} . By [BS, 18.2.3], $F(J)$ is isomorphic to $k[x]$, where $k = A/\mathfrak{m}$ since a is independent analytically in I_1 . We also have $J^i \cap I_i \mathfrak{m} = J^i \mathfrak{m}$. Then

$$F(J) \hookrightarrow F(\mathfrak{F}).$$

Now by [V, Example 9.3.1] or [GP, Theorem 2.6.1]

$$F(\mathfrak{F}) \simeq \bigoplus_{i=1}^e F(J)(-b_i) \bigoplus_{j=1}^f (F(J)/a^{c_j} F(J))(-d_j).$$

Let assume $b_1 \leq \dots \leq b_e$ and $d_1 \leq \dots \leq d_f$. Hence

$$H_{F(\mathfrak{F})}(x) = \frac{x^{b_1} + \dots + x^{b_e} + (1 - x^{c_1})x^{d_1} + \dots + (1 - x^{c_f})x^{d_f}}{1 - x}.$$

Observe that

$$\begin{aligned} r_J(\mathfrak{F}) &= r_J(F(\mathfrak{F})) = \max\{b_e, d_f\} \\ \text{reg } F(\mathfrak{F}) &= \max\{b_e, c_j + d_j - 1\} \end{aligned} \tag{4.3}$$

By the hypothesis I_1 contain a regular element. Note that since J is a reduction of I_1 , a is also a regular element. Let $r := r_J(\mathfrak{F})$. If $n \geq r$ then $I_n = a^{n-r} I_r$. Hence

$$\frac{I_n}{\mathfrak{m} I_n} = \frac{a^{n-r} I_r}{a^{n-r} \mathfrak{m} I_r}.$$

Then we have the map

$$\frac{I_r}{\mathfrak{m} I_r} \longrightarrow \frac{I_n}{\mathfrak{m} I_n},$$

multiplication by a^{n-r} . It is easy to show that the map is bijective. Thus $\mu(I_n) = \mu(I_r)$ for $n \geq r$. Then

$$H_{F(\mathfrak{F})}(x) = \sum_{n \geq 0} \mu(I_n) x^n = \frac{1 + (\mu(I_1) - 1)x + \dots + (\mu(I_r) - \mu(I_{r-1}))x^r}{1 - x}.$$

Comparing both the expression of the Hilbert series, it follow that $c_j + d_j \leq r$ and then $d_f \leq r - 1$. In particular $r := r_J(\mathfrak{F}) = b_e$. Therefore $\text{reg } F(\mathfrak{F}) = r_J(\mathfrak{F})$. \square

We denote $H_{R(\mathfrak{F})_+}^i(M)$ by $H^i(M)$.

Theorem 4.3. *Let (A, \mathfrak{m}) a Noetherian local ring and \mathfrak{F} a good-filtration such that $\ell := s(\mathfrak{F}) = 1$. Then $\text{reg } F(\mathfrak{F}) \leq \text{reg } G(\mathfrak{F})$. Furthermore, if $\text{grade } I_1 = 1$ we have $\text{reg } F(\mathfrak{F}) = \text{reg } G(\mathfrak{F}) = r(\mathfrak{F})$.*

Proof. Since $\ell = 1$, $\sqrt{R(\mathfrak{F})_+} = \sqrt{(x_1)}$. As $H_{R(\mathfrak{F})_+}^i(M) = 0$ para $i > \text{ara}(R(\mathfrak{F})_+)$ and $\text{ara}(R(\mathfrak{F})_+) \leq 1$, it follows that $H^i(M) = 0$ for $i > 1$. From exact sequence (4.2), we have the long exact sequence

$$\begin{aligned} 0 \rightarrow H^0(\mathfrak{m}G(\mathfrak{F})) &\rightarrow H^0(G(\mathfrak{F})) \rightarrow H^0(F(\mathfrak{F})) \\ &\rightarrow H^1(\mathfrak{m}G(\mathfrak{F})) \rightarrow H^1(G(\mathfrak{F})) \rightarrow H^1(F(\mathfrak{F})) \rightarrow 0. \end{aligned} \quad (4.4)$$

Hence $a_0(\mathfrak{m}G(\mathfrak{F})) \leq a_0(G(\mathfrak{F}))$ e $a_1(F(\mathfrak{F})) \leq a_1(G(\mathfrak{F}))$. From exact sequence (4.1), we have the long exact sequence

$$\begin{aligned} 0 \rightarrow H^0(R(\mathfrak{F})) &\rightarrow H^0(R(\mathcal{F})) \rightarrow H^0(\mathfrak{m}G(\mathfrak{F})(-1)) \\ &\rightarrow H^1(R(\mathfrak{F})) \rightarrow H^1(R(\mathcal{F})) \rightarrow H^1(\mathfrak{m}G(\mathfrak{F})(-1)) \rightarrow 0. \end{aligned} \quad (4.5)$$

Hence $a_1(\mathfrak{m}G(\mathfrak{F})(-1)) = a_1(\mathfrak{m}G(\mathfrak{F})) + 1 \leq a_1(R(\mathcal{F}))$ and by the Lemma 4.1 we have

$$a_1(\mathfrak{m}G(\mathfrak{F})) \leq a_1(R(\mathfrak{F})).$$

By hypothesis $\ell = 1$ and by a remark of [T, p. 2818], we have $H^1(G(\mathfrak{F})) \neq 0$. Hence, by the Theorem 3.2, we have $a_1(R(\mathfrak{F})) \leq a_1(G(\mathfrak{F}))$. Then $a_1(\mathfrak{m}G(\mathfrak{F})) \leq a_1(G(\mathfrak{F}))$. Therefore

$$\text{reg } \mathfrak{m}G(\mathfrak{F}) \leq \text{reg } G(\mathfrak{F}).$$

By using the exact sequence (4.2) and [BS, Exercise 15.2.15] we have

$$\text{reg } F(\mathfrak{F}) \leq \max\{\text{reg } G(\mathfrak{F}), \text{reg } \mathfrak{m}G(\mathfrak{F}) - 1\} = \text{reg } G(\mathfrak{F}).$$

Now let suppose that $\text{grade } I_1 = 1$. By the Lemma 4.2, we have $\text{reg } F(\mathfrak{F}) = r_J(\mathfrak{F})$, for any minimal reduction J of \mathfrak{F} . Furthermore by [HZ, Proposition 3.6], $\text{reg } G(\mathfrak{F}) = r_J(\mathfrak{F})$. Therefore $\text{reg } F(\mathfrak{F}) = \text{reg } G(\mathfrak{F}) = r(\mathfrak{F})$. \square

Corollary 4.4. *Let (A, \mathfrak{m}) be a Noetherian local ring and \mathfrak{F} a good-filtration such that $s(\mathfrak{F}) := \dim F(\mathfrak{F}) = 1$. If (A, \mathfrak{m}) is Cohen-Macaulay and \mathfrak{F} is equimultiple we have $\operatorname{reg} F(\mathfrak{F}) = \operatorname{reg} G(\mathfrak{F}) = r(\mathfrak{F})$.*

Proof. Since A is Cohen-Macaulay and \mathfrak{F} is equimultiple, by [HZ, Lemma 2.8] and by [GP, Corollary 7.7.10], we have $s(\mathfrak{F}) = s(I_1) = h(I_1) = \operatorname{grade} I_1$. The result follows by the Theorem 4.3. \square

Lemma 4.5. *Let (A, \mathfrak{m}) be a local ring and $a \in I_1$. If a^* is a regular element of $G(\mathfrak{F})$, then*

$$\frac{F(\mathfrak{F})}{a^o F(\mathfrak{F})} \cong F(\mathfrak{F}/(a)).$$

Proof. Since a^* is a regular element of $G(\mathfrak{F})$ it is easy to show that $aA \cap I_n = aI_{n-1}$ for any $n \geq 0$. Note that

$$F(\mathfrak{F}/(a)) = \bigoplus_{n \geq 0} \frac{\frac{I_n + aA}{aA}}{\frac{\mathfrak{m}}{aA}(\frac{I_n + aA}{aA})} = \bigoplus_{n \geq 0} \frac{\frac{I_n + aA}{aA}}{\frac{\mathfrak{m}I_n + aA}{aA}} \simeq \bigoplus_{n \geq 0} \frac{I_n + aA}{\mathfrak{m}I_n + aA}.$$

The natural map

$$I_n \longrightarrow \frac{I_n + aA}{\mathfrak{m}I_n + aA}$$

induces a isomorphism

$$\frac{I_n}{\mathfrak{m}I_n + (I_n \cap aA)} \simeq \frac{I_n + aA}{\mathfrak{m}I_n + aA}.$$

Note that

$$\left(\frac{F(\mathfrak{F})}{a^o F(\mathfrak{F})} \right)_n = \frac{F(\mathfrak{F})_n}{(a^o F(\mathfrak{F}))_n} = \frac{\frac{I_n}{\mathfrak{m}I_n}}{\frac{aI_{n-1} + \mathfrak{m}I_n}{\mathfrak{m}I_n}} \simeq \frac{I_n}{aI_{n-1} + \mathfrak{m}I_n} = \frac{I_n}{(aA \cap I_n) + \mathfrak{m}I_n}.$$

\square

Theorem 4.6. *Let (A, \mathfrak{m}) be a Noetherian local ring and \mathfrak{F} a good-filtration. Let suppose $\operatorname{grade} I_1 = \ell$ and $\operatorname{grade} G(\mathfrak{F})_+ \geq \ell - 1$. Then $\operatorname{reg} F(\mathfrak{F}) \geq \operatorname{reg} G(\mathfrak{F})$. Furthermore, if $\operatorname{depth} F(\mathfrak{F}) \geq \ell - 1$, then*

$$\operatorname{reg} F(\mathfrak{F}) = \operatorname{reg} G(\mathfrak{F}).$$

Proof. If $\ell = 1$, by the Theorem 4.3 the result is true. Then we can suppose $\ell \geq 2$. By [JV, Proposition 2.2], there exist generators x_1, \dots, x_ℓ of a minimal reduction J of I_1 such that $x_1^*, \dots, x_\ell^* \in I_1/I_2$ is filter-regular sequence of $G(\mathfrak{F})$ and $x_1^o, \dots, x_{\ell-1}^o \in I_1/\mathfrak{m}I_1$ is filter-regular of $F(\mathfrak{F})$. By hypothesis $\text{grade } G(\mathfrak{F})_+ \geq \ell - 1$. Thus $x_1^*, \dots, x_{\ell-1}^*$ is $G(\mathfrak{F})$ -regular due to [HM, Lemma 2.1]. We denote $\bar{\mathfrak{F}} = \frac{\mathfrak{F}}{(x_1, \dots, x_{\ell-1})}$. By [HZ, Lemma 3.4],

$$G(\bar{\mathfrak{F}}) \simeq G(\mathfrak{F})/(x_1^*, \dots, x_{\ell-1}^*).$$

By Lemma 4.5,

$$F(\bar{\mathfrak{F}}) \simeq F(\mathfrak{F})/(x_1^o, \dots, x_{\ell-1}^o).$$

Since $x_1^*, \dots, x_{\ell-1}^*$ are regular, $\text{reg } G(\bar{\mathfrak{F}}) = \text{reg } G(\mathfrak{F})$. By [JV, Proposition 2.5], $\dim F(\bar{\mathfrak{F}}) = \dim F(\mathfrak{F}) - (\ell - 1) = 1$. By using [HM, Proposition 3.5] and [BH, Proposition 1.2.10(d)], we have

$$\text{grade } \frac{I_1}{(x_1, \dots, x_{\ell-1})} = \text{grade } I_1 - (\ell - 1) = 1.$$

Thus, by Theorem 4.3 we achieve $\text{reg } F(\bar{\mathfrak{F}}) = \text{reg } G(\bar{\mathfrak{F}}) = \text{reg } G(\mathfrak{F})$. By [BS, Proposition 18.3.11], $\text{reg } F(\bar{\mathfrak{F}}) \leq \text{reg } F(\mathfrak{F})$ and it implies that

$$\text{reg } G(\mathfrak{F}) \leq \text{reg } F(\mathfrak{F}).$$

Now, let assume $\text{depth } F(\mathfrak{F}) \geq \ell - 1$. Then $x_1^o, \dots, x_{\ell-1}^o$ is $F(\mathfrak{F})$ -regular. Then $\text{reg } F(\mathfrak{F}) = \text{reg } F(\bar{\mathfrak{F}})$. Therefore $\text{reg } F(\mathfrak{F}) = \text{reg } G(\mathfrak{F})$. \square

Proposition 4.7. *Let (A, \mathfrak{m}) a Noetherian local ring and \mathfrak{F} a good filtration. If $\text{reg } R(\mathcal{F}) \leq \text{reg } R(\mathfrak{F})$, then*

$$\text{reg } F(\mathfrak{F}) = \text{reg } G(\mathfrak{F}).$$

Proof. By using the properties of regularity for exact sequences [BS, Exercise 15.2.15], we can conclude by the exact sequence (4.1) that

$$\text{reg } \mathfrak{m}G(\mathfrak{F})(-1) = \text{reg } \mathfrak{m}G(\mathfrak{F}) + 1 \leq \max\{\text{reg } R(\mathfrak{F}) - 1, \text{reg } R(\mathcal{F})\}.$$

But $\text{reg } R(\mathcal{F}) \leq \text{reg } R(\mathfrak{F})$, then from the exact sequence (4.2)

$$\text{reg } F(\mathfrak{F}) \leq \max\{\text{reg } \mathfrak{m}G(\mathfrak{F}) - 1, \text{reg } G(\mathfrak{F})\} \leq \text{reg } R(\mathfrak{F})$$

since $\text{reg } R(\mathfrak{F}) = \text{reg } G(\mathfrak{F})$ (Corollary 3.4). Thus $\text{reg } R(\mathfrak{F}) \leq \text{reg } G(\mathfrak{F})$ as we required. \square



Proposition 4.8. *Let (A, \mathfrak{m}) be a Noetherian local ring such that $\text{grade } I_1 > 0$. Let suppose that $I_n = \mathfrak{m}I_{n-1}$ for $n \gg 0$. Then*

$$\text{reg } R(\mathfrak{F}) = \text{reg } G(\mathfrak{F}).$$

Proof. Let n_0 be such that $I_n = \mathfrak{m}I_{n-1}$ for $n \geq n_0$. Note that $R(\mathfrak{F})_+^{n_0} \mathfrak{m}G(\mathfrak{F}) = 0$. Hence $R(\mathfrak{F})_+^{n_0} \subseteq \text{Ann}(\mathfrak{m}G(\mathfrak{F}))$ and it implies $V(\text{Ann}(\mathfrak{m}G(\mathfrak{F}))) \subseteq V(R(\mathfrak{F})_+^{n_0})$. By [HIO, Corollary 35.19],

$$H_{R(\mathfrak{F})_+}^i(\mathfrak{m}G(\mathfrak{F})) = H_{R(\mathfrak{F})_+^{n_0}}^i(\mathfrak{m}G(\mathfrak{F})) = 0,$$

for $i > 0$. Since $R(\mathfrak{F})_+^{n_0} \mathfrak{m}G(\mathfrak{F}) = 0$,

$$H_{R(\mathfrak{F})_+}^0(\mathfrak{m}G(\mathfrak{F})) = \mathfrak{m}G(\mathfrak{F}).$$

If $\mathfrak{m}G(\mathfrak{F}) = 0$, we have $\mathfrak{m}I_n = I_{n+1}$ for all n . Thus $F(\mathfrak{F}) = G(\mathfrak{F})$ and the proposition follows trivially. Let suppose that $\mathfrak{m}G(\mathfrak{F}) \neq 0$. From the exact sequence (4.2) we can conclude that

$$0 \rightarrow H^0(\mathfrak{m}G(\mathfrak{F})) \rightarrow H^0(G(\mathfrak{F})) \rightarrow H^0(F(\mathfrak{F})) \rightarrow 0$$

and $H^i(G(\mathfrak{F})) \cong H^i(F(\mathfrak{F}))$ for $i > 0$. Hence $a_0(F(\mathfrak{F})) \leq a_0(G(\mathfrak{F}))$ and $a_i(G(\mathfrak{F})) = a_i(F(\mathfrak{F}))$ for $i > 0$. We claim that

$$\text{depth } G(\mathfrak{F}) = \text{grade}(G(\mathfrak{F})_+, G(\mathfrak{F})) = \text{grade}(R(\mathfrak{F})_+, G(\mathfrak{F}))$$

is equal zero. If $\text{depth } G(\mathfrak{F}) > 0$, by [BS, Theorem 6.2.7], $H^0(G(\mathfrak{F})) = 0$. Then, from the exact sequence above, $H^0(\mathfrak{m}G(\mathfrak{F})) = 0$, a contradiction. By [HZ, Proposition 3.5] and by the hypothesis

$$a_0(F(\mathfrak{F})) \leq a_0(G(\mathfrak{F})) < a_1(G(\mathfrak{F})) = a_1(F(\mathfrak{F})).$$

Therefore

$$\text{reg } F(\mathfrak{F}) = \max\{a_i(F(\mathfrak{F}))+i : i \geq 1\} = \max\{a_i(G(\mathfrak{F}))+i : i \geq 1\} = \text{reg } G(\mathfrak{F}).$$

□

Proposition 4.9. *Let (A, \mathfrak{m}) be a Noetherian local ring and \mathfrak{F} a good filtration such that $\text{grade } I_1 > 0$. Let suppose that $\mathfrak{m}G(\mathfrak{F})$ is $R(\mathfrak{F})$ -module Cohen-Macaulay of dimension ℓ . Then*

- (i) $\text{reg } F(\mathfrak{F}) \leq \text{reg } G(\mathfrak{F})$;
- (ii) if $a_\ell(R(\mathcal{F})) - 1 < a_\ell(R(\mathfrak{F}))$ then $\text{reg } F(\mathfrak{F}) = \text{reg } R(\mathfrak{F})$;
- (iii) if $a_\ell(R(\mathcal{F})) - 1 = a_\ell(R(\mathfrak{F}))$ then $\text{reg } \mathfrak{m}G(\mathfrak{F}) \leq \text{reg } R(\mathfrak{F})$ and $\text{reg } F(\mathfrak{F}) \leq \text{reg } R(\mathfrak{F})$.

Furthermore, if $\text{reg } \mathfrak{m}G(\mathfrak{F}) < \text{reg } G(\mathfrak{F})$ then $\text{reg } F(\mathfrak{F}) = \text{reg } R(\mathfrak{F})$.

Proof. Since $\mathfrak{m}G(\mathfrak{F})$ is Cohen-Macaulay and by [BS, Theorem 6.2.7 and Theorem 6.1.2], $H^i(\mathfrak{m}G(\mathfrak{F})) = 0$ for $i \neq \ell$. From the exact sequence (4.1) we have

$$\dots \rightarrow H^i(R(\mathfrak{F})) \rightarrow H^i(R(\mathcal{F})) \rightarrow H^i(\mathfrak{m}G(\mathfrak{F})(-1)) \rightarrow H^{i+1}(R(\mathfrak{F})) \rightarrow \dots$$

Then $H^i(R(\mathfrak{F})) \cong H^i(R(\mathcal{F}))$ for $i \neq \ell$ so that $a_i(R(\mathcal{F})) = a_i(R(\mathfrak{F}))$ for $i \neq \ell$.

First, let prove (ii). By hypothesis we have $a_\ell(R(\mathcal{F})) \leq a_\ell(R(\mathfrak{F}))$. Therefore $a_i(R(\mathcal{F})) \leq a_i(R(\mathfrak{F}))$ for all i so that $\text{reg } R(\mathcal{F}) \leq \text{reg } R(\mathfrak{F})$. From the Proposition 4.7, $\text{reg } F(\mathfrak{F}) = \text{reg } R(\mathfrak{F})$.

Now, let prove (iii). If $a_\ell(R(\mathcal{F})) - 1 = a_\ell(R(\mathfrak{F}))$ we have

$$\text{reg } R(\mathcal{F}) \leq \text{reg } R(\mathfrak{F}) + 1$$

since $a_i(R(\mathcal{F})) = a_i(R(\mathfrak{F}))$ for $i \neq \ell$. From the exact sequence (4.1) we have

$$\begin{aligned} \text{reg } (\mathfrak{m}G(\mathfrak{F})(-1)) &= \text{reg } \mathfrak{m}G(\mathfrak{F}) + 1 \\ &\leq \max\{\text{reg } R(\mathfrak{F}) - 1, \text{reg } R(\mathcal{F})\} \\ &\leq \text{reg } R(\mathfrak{F}) + 1. \end{aligned}$$

From the exact sequence (4.2),

$$\text{reg } F(\mathfrak{F}) \leq \max\{\text{reg } \mathfrak{m}G(\mathfrak{F}) - 1, \text{reg } G(\mathfrak{F})\} \leq \text{reg } R(\mathfrak{F}).$$

Hence (iii) is proved. By Lemma 4.1, $a_\ell(R(\mathcal{F})) - 1 \leq a_\ell(R(\mathfrak{F}))$. Then by (ii) and (iii), we have (i).

Finally, let assume $\text{reg } \mathfrak{m}G(\mathfrak{F}) < \text{reg } G(\mathfrak{F})$. From the exact sequence (4.2),

$$\text{reg } G(\mathfrak{F}) \leq \max\{\mathfrak{m}G(\mathfrak{F}), \text{reg } F(\mathfrak{F})\}. \quad (4.6)$$

Since $\text{reg } \mathfrak{m}G(\mathfrak{F}) < \text{reg } G(\mathfrak{F})$, by (4.6),

$$\max\{\mathfrak{m}G(\mathfrak{F}), \text{reg } F(\mathfrak{F})\} = \text{reg } F(\mathfrak{F}).$$

Thus $\text{reg } G(\mathfrak{F}) \leq \text{reg } F(\mathfrak{F})$. By Corollary 3.4, $\text{reg } G(\mathfrak{F}) = \text{reg } R(\mathfrak{F})$. Hence $\text{reg } R(\mathfrak{F}) \leq \text{reg } F(\mathfrak{F})$. The other inequality already was proved. \square

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SÉRIE MATEMÁTICA

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